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REVIEW

The Current Status, Hotspots, and Development Trends of Nanoemulsions: A Comprehensive Bibliometric Review

Guojun Sun[1], Liying Wang[1], Zuojun Dong[1], Yanxiao Zhang[1], Yan Yang[1], Miao Hu[2], Hui Fang[3,4]

[1]Institute of Pharmaceutical Preparations, Department of Pharmacy, Zhejiang University of Technology, Hangzhou, People's Republic of China; [2]Zhejiang Guangsha Vocational and Technical University of Construction, Jinhua, People's Republic of China; [3]Library, Zhejiang University of Technology, Hangzhou, People's Republic of China; [4]Institute of Information Resource, Zhejiang University of Technology, Hangzhou, People's Republic of China

Correspondence: Hui Fang, Institute of Information Resource, Zhejiang University of Technology, Hangzhou, People's Republic of China, Email fanghui@zjut.edu.cn

Abstract: Nanoemulsions, which are characterized by their nanometer-scale droplets, have gained significant attention in different fields, such as medicine, food, cosmetics, and agriculture, because of their unique properties. With an increasing number of countries engaging in research on nanoemulsions, interest in their properties, preparation methods, and applications has increased. Hence, tracing the relevant research on nanoemulsions published in the past ten years on a global scale, by conducting data mining and visualization analysis on a sufficiently large text dataset through bibliometrics, sorting out and summarizing certain indicators, the development history, research status and research hotspots in the field of nanoemulsions can be clearly revealed, providing reference value and significance for subsequent research. This bibliometric review examines the research landscape of nanoemulsions from 2013–2023 via the SCI-E and SSCI databases, providing insights into the current status, hotspots, and future trends of this field. To offer a comprehensive overview, this analysis includes publication counts, author keywords, institutional contributions, research areas, prolific authors, highly cited papers and hot research papers. The findings reveal that China led in nanoemulsions research, followed by USA, India, and Brazil, with the University of Massachusetts emerging as a key player with the highest average number of citations per article (ACPP) and h-index. Food Chemistry, Pharmaceutics, and the Journal of Drug Delivery Science and Technology are among the top journals publishing in this area. Chemistry, pharmacology, and pharmacy emerged as the primary research domains, with McClements DJ as the most prolific and influential author. In keyword analysis, essential oil nanoemulsions are currently the main preparation direction, and various characteristics of nanoemulsions, such as their bioavailability, stability, biocompatibility, and antioxidant and antibacterial properties, have also been studied extensively. Research hotspots are focused mostly on the development of new applications and technologies for nanoemulsions.

Keywords: nanoemulsions, bibliometrics, bioavailability, essential oil, drug delivery, keyword analysis

Introduction

Nanoemulsions are two immiscible liquids with droplet diameters between 20 nm and 500 nm that are mixed and stabilized via suitable emulsifiers to create a two-phase dispersion system, including two-phase systems such as O/W and W/O nanoemulsions, as well as multiple nanoemulsions such as W/O/W.[1] Surfactants reduce the droplet size of the nanoemulsions by reducing the interfacial tension γ between the oil phase and the water phase. The dosage of surfactants required to produce the minimum droplet size depends on its activity concentration in bulk.[2] The extremely small size of nanoemulsions results in different characteristics from those of conventional emulsions,[3] allowing for them to maintain kinetic stability for a long time, in addition to their high specific surface area, transparent appearance, and adjustable rheology. Owing to their unique properties, nanoemulsions have been widely used in various fields[4] such as drug delivery,[5] food,[6] cosmetics[7] and pesticides.[8]

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In the pharmaceutical industry, owing to the hydrophobic structure inside the nanoemulsions, it can be used as a carrier for poorly soluble drugs, improving their solubility and bioavailability,[9] reducing the first-pass effect of the liver, promoting the lymphatic transport and absorption of drugs, and facilitating better anti-inflammatory and antioxidant capabilities.[10] Currently, it has been developed for oral administration,[11] dermal administration,[12] ocular administration,[13] pulmonary administration,[14] intranasal administration,[15] and drugs such as cyclosporine[16] and saquinavir[17] have been approved for marketing in the form of nanoemulsions. In recent years, nanoemulsions have been widely studied in the areas of cancer treatment,[18] RNA therapy,[19] photodynamic therapy,[20] gene therapy,[21] immunotherapy[22] and vaccine adjuvants.[23] Shukla et al showed good efficacy in treating breast cancer bone metastasis by crystallizing self-assembled nanoemulsions into porous crystals of alendronate sodium and oleanolic acid, which prolonged the drug's action time in the body and prevented bone loss while treating cancer.[24] Borrajo et al developed an ionizable nanoemulsions for RNA delivery. Compared with lipid nanoparticles, nanoemulsions can better overcome the blood–brain barrier, exhibit good cell viability and transfection efficiency, and have greater diffusion properties.[25] Nanoemulsions can also be used in medical imaging treatments, such as the encapsulation of photosensitizer PSs in photodynamic therapy, which can reduce the tendency of PSs self-aggregation, increase permeability and retention, and improve the efficiency of photodynamic therapy.[26] Given the surface tunability of nanoemulsions, while drugs are encapsulated internally, they can also be modified with targeted fragments on the surface to achieve targeting.[27] Li et al modified paclitaxel and docosahexaenoic acid lipid nanoemulsions with folic acid, and the experimental results revealed increased cellular uptake rates, indicating synergistic effects in the treatment of breast cancer.[28] Nanoemulsions promote penetration and can be used as liquid droplets or sprays.[29] When used for topical administration to the skin, nanoemulsions easily penetrate the stratum corneum of the skin, promote the absorption of active ingredients, and have good compliance. Currently, people are more likely to make drugs into nanoemulsions-based hydrogel transdermal patches. Rai et al prepared nanoemulsions and polyvinyl alcohol hydrogel films from carbamazepine, which reduced the moisture content and moisture absorption rate and promoted skin permeability.[30]

In the food industry, nanoemulsions are usually used to encapsulate and deliver nutrients such as fat-soluble vitamins,[31] plant sterols,[32] beta-carotene,[33] flavonoids,[34] and cinnamaldehyde[35] in food, which can increase their digestibility, encapsulation efficiency and bioavailability.[36] In addition, nanoemulsions can also be used for the preparation of biodegradable coatings, edible films,[37] and antibacterial coatings.[38] An essential oil nanoemulsions is a common preparation form. Essential oils are natural hydrophobic volatile ingredients with excellent antioxidant, anti-inflammatory, antibacterial, and insecticidal properties and are recognized as safe and effective.[39] Compared with conventional essential oils, essential oil nanoemulsions have better antioxidant properties[40] and antibacterial properties[41] and are especially suitable for controlling microbial growth with essential oils. They can be used to deliver various natural substances with antimicrobial activity,[42] extending their shelf-life. Researchers have made many natural products, such as carvacrol,[43] thyme oil,[44] peppermint oil and cinnamon oil[45] into essential oil antibacterial nanoemulsions, all of which show good antimicrobial activity. The nanoemulsions form can also mask the irritating taste and aroma of conventional essential oils[46] while reducing their impact on human health.[47] Essential oil nanoemulsions can also be used as natural food preservatives.[48] Yang et al prepared a sodium alginate/tea tree essential oil nanoemulsions containing TiO_2 nanoparticles, which showed good effects on postharvest quality assurance and prevention of anthracnose in banana fruit.[49]

In the environmental protection industry, such as the manufacture and use of pesticides such as insecticides, the superior performance of nanoemulsions has gradually been revealed. Due to their high efficiency, safety and environmental protection characteristics, the number of studies on nanoemulsions in the environmental field is increasing. Researchers have made nanoemulsions insecticides from sulfoxaflor,[50] pyraclostrobin,[51] cyhalothrin,[52] and fennel essential oils[53] that are promising pesticides. Nasser et al prepared a new nanoemulsions insecticide using ginger essential oil and basil essential oil as raw materials to prevent white ant activity in Taiwan and proposed a sustainable and environmentally friendly natural plant-derived insecticide.[54] Gupta et al prepared and characterized a chitosan-encapsulated thyme oil and musk essential oil nanoemulsions and reported that it had control effects on various major mosquito species.[55] Environmental protection is a major goal that researchers have pursued. The future trend is to make more natural plant essential oils[56] into nanoemulsions forms for use as pesticides that are safer and more efficient, which can not only reduce costs and application amounts but also protect the environment to a greater extent.

The methods used to prepare nanoemulsions can be divided into two categories according to their energy consumption: high-energy methods and low-energy methods. High-energy preparation methods include high-pressure homogenization,[57] ultrasonic methods,[58] and microfluidization,[59] whereas low-energy preparation methods include the phase transition temperature method[60] and self-emulsification method.[61] The high-energy method relies on the strong destructive force generated by mechanical devices, such as shear force, turbulence, cavitation, and ultrasonic disruption, to reduce size.[62] The current method commonly used by researchers involves subjecting coarse emulsions to high-pressure homogenization followed by ultrasonic treatment. Palla et al used high-speed homogenization followed by ultrasonic treatment with a curcumin-loaded monoglyceride gel to prepare a nanoemulsions of gel oil particles, resulting in a nanoemulsions with at least 10 months of stability and high encapsulation efficiency.[63] Nonetheless, the high-energy methods for preparing nanoemulsions have high energy consumption and high cost and are not suitable for heat-sensitive products. Low-energy methods depend on the chemical energy stored in the system, such as the characteristics of surfactants, oils, and water systems, and require only slight agitation to achieve nanoemulsification. Alam et al used a low-energy emulsification method to prepare babchi oil nanoemulsions-based hydrogels and explored their therapeutic effects on psoriasis. The results revealed that the nanogel formulation had better drug permeability.[64] Low-energy emulsification methods are more convenient and energy efficient but require higher surfactant concentrations to stabilize nanodroplets. Moreover, more systematic research is necessary in the optimization of nanoemulsions formulations, such as investigation of the amount of surfactant used, the type of oil phase, and other factors. The degradation mechanism of nanoemulsions depends on its system compositions such as the type of oil phase, the type of surfactants, the relative concentration, the pH value, the ionic strength and the type of solvent, so its kinetic stability can be improved by the addition of stabilizers, such as emulsifiers, texture modifiers, weight enhancers or maturing agents.[65] At the same, as a model system, nanoemulsions can enhance the colloidal assembly of complex emulsion systems and the understanding of rheology.[66]

The stability of nanoemulsions is also a popular topic among researchers. In addition to common instability mechanisms such as stratification, flocculation, and coalescence, Ostwald ripening is the main instability mechanism of nanoemulsions.[67–69] By increasing the amount of emulsifier or adding long-chain triglycerides, Ostwald ripening can be inhibited, and the stability of nanoemulsions can be enhanced, but this will inevitably affect safety performance, as commonly used emulsifiers such as the surfactants Tween[70] and Span[71] often face limitations due to potential toxicity risks, which pose a threat to the safety of nanoemulsions products. Currently, researchers are developing new emulsifiers for nanoemulsions, such as plant proteins, whey protein, and soy protein concentrate.[72] Saponins, such as glycyrrhizic acid,[73] camellia saponin,[74] and Q-Naturale,[75] are the most important class of natural emulsifiers due to their high surface activity, amphiphilicity, abundant sources, and low cost, which promote their use in commercial production.[76] There are also other natural polymers, such as gum Arabic,[77] maltodextrin,[78] and lecithin,[79] that can be used as natural emulsifiers. These natural emulsifiers are biocompatible, biodegradable, and environmentally friendly. Using them individually or in combination can achieve satisfactory results. Further exploration of their sources, production, emulsifying capabilities, and performance comparison is urgently needed to determine their future prospects.[80]

At present, research on nanoemulsions has focused mainly on seeking more extensive applications, better stability, lower cost and larger scale preparation methods, and safer and more effective emulsifiers. To date, the literature reviews on nanoemulsions published have described their properties, preparation methods, stability, and applications individually or in one aspect, but there has been no comprehensive bibliometric review of nanoemulsions considering the countries/regions, hotspots, and development trends, now there is only one bibliometric review of the use of nanoemulsions and/or in-situ gels for ocular drug delivery systems during 2011–2021 by Fatimah et al. When researchers or institutions, including pharmaceutical, food, pesticide, and other companies or research institutes, seek a comprehensive overview of the current research hotspots of nanoemulsions, there is often a lack of relevant information, by conducting data mining and visualization analysis on a sufficiently large text dataset through bibliometrics, sorting out and summarizing certain indicators, the development history, research status and research hotspots in the field of nanoemulsions can be clearly revealed, providing reference value and significance for subsequent research. This study aimed to scientifically investigate global research progress in nanoemulsions research from 2013–2023 and analyze the literature considering different analytical standards and perspectives, with the aim of exploring further research hotspots and future development tendencies. Bibliometrics refers to the quantitative and visual analysis of published academic research in a specific field via mathematical and statistical methods. It can reveal subtle differences in the development of a particular field, as well as emerging hotspots in that field.[81] Currently, it has been extensively applied across a wide variety of disciplines

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and industries, such as medical science,[82] pharmaceutical sciences,[83–86] economics,[87] management science,[88] social sciences,[89–91] environmental sciences,[92,93] and materials science.[94–96] To this end, this study used bibliometric methods to conduct quantitative and visual analyses of the following aspects of nanoemulsions: 1) main contributing countries; 2) major contributing institutions; 3) common research fields; 4) the most productive journal; 5) keyword analysis; 6) the most prolific author; and 7) hot papers and highly cited Essential Science Indicators (ESI) papers. In addition, the research hotspots and future trends in the field of nanoemulsions are discussed.

Method and Data Handling

Data Collection

We selected the Web of Science (WOS) Core Database (version ©2024 Clarivate), which, owing to its rigorous journal selection, was used to discover researchers' scientific outputs and disciplinary developments. Data were collected on March 18, 2024, through the WOS Database Citation Index Science Citation Index Expended (SCI-E) and Social Science Citation Index (SSCI) databases via the search strategy "nanoemulsions*" or "nano emulsion*" in the 'subject' field, with document types limited to 'Article' and 'Review article'. The publication year was set from 2013–2023, resulting in a total of 8561 eligible publications after retrieval.

Data Input and Deduplication

The intact records of all acquired documents were downloaded and input into Derwent Data Analyzer (DDA) for processing and then classified according to the countries, institutions, research fields, journals, keywords, authors, and other field lists. In addition, for each item field set of the list, DDA employs an inherent cleaning tool that automatically removes duplicate data.

Data Partition and Merging

DDA software can perform data cleaning, multiview data mining and visual analysis. After the DDA software automatically processes duplicate items, the items still need to be manually confirmed, split and merged. For example, articles from England, Scotland, Northern Ireland and Wales were all counted as United Kingdom articles, whereas those from Hong Kong, Macao and Taiwan were incorporated into China's articles. Additionally, articles from different campuses of the same university were grouped under a single article for that university.

Data Analysis and Visualization

After automatic and manual cleaning of the DDA data and matrix analysis, bubble charts, cluster maps and Sankey diagrams were drawn. Cluster maps can show the cooperative relationships between institutions, whereas bubble charts display the development trends in research fields, journals, and keywords, revealing useful information. The main areas of bibliometrics were also analyzed in the form of tables, such as countries/regions, institutions, research fields, journals, authors, highly cited papers and hot papers, while bibliometric indicators such as citations, average annual citations, and h-index, were used to study nanoemulsions from different perspectives. Moreover, some studies published online in advance usually have publication dates one to two years later. For a unified analysis, we set their publication year as that of online publishing.

Results

Number and Type of Publications

The 8561 papers acquired via the above search strategy were mainly research articles (7489; 87.48%) and comprehensive articles (1072; 12.52%). Some publications were not solely classified as research or review articles but also comprise other categories, such as conference proceedings papers (63; 0.74%), papers published online (52; 0.61%), withdrawn publications (15; 0.18%), book chapters (9; 0.10%), and publications expressing concern (1; 0.013%). The vast majority of the articles were published in English (8537; 99.72%), and the rest were published in Portuguese (11; 0.13%), Chinese (4; 0.047%), Japanese (3; 0.035%), Polish (2; 0.025%), German (2; 0.025%), Czech (1; 0.009%) and Serbo-Croatian (1; 0.009%).

The growth trend of the number of publications and citation frequency in the field of nanoemulsions research from 2013–2023 is described (Figure 1), including the proportions of research from China, USA, and India as the top three

Figure 1 Annual trends in the number of published articles related to nanoemulsions.

countries in terms of the number of publications. The number of publications on this topic increased from 285 in 2013 to 1142 in 2023 and is increasing annually. China was in the leading position in terms of the aggregate number of publications for most of the time. USA started research on nanoemulsions earlier, so it published the most articles from 2013–2016. Although research on nanoemulsions began lately in India, its growth momentum has been strong in the past three years, and the growth rate of research from India has exceeded that of USA.

Number of Countries and Publications

A review of the 8561 publications related to nanoemulsions research shows that 110 countries have contributed to this field. The top 20 countries/regions in terms of the number of publications and citations are described (Table 1). Asia had the most countries/regions, with a total of eight, Europe had six, America had four, and Africa and Oceania each had one.

The three countries/regions that have made the largest contributions are China, USA and India. Since 2013, these three countries have published 1839, 1268 and 1248 articles, respectively, accounting for 21.5%, 14.8% and 14.6% of the total, far exceeding those of other countries and taking an absolute leading position. Brazil (862), Iran (621), Saudi Arabia (582), Egypt (463), Spain (370), South Korea (332), Italy (296), France (282) and Malaysia (269) are also highly productive countries. With respect to the impact of publications, the USA ranked first, with a total number of citations of 49,170; China ranked second, with 48,358 citations; and India ranked third, with 36,429 citations. The top three countries far outweighed Brazil, which ranked fourth, with 17,237 citations. To reflect the development of individual or collective research clearly, we also introduce the average number of citations per article (ACPP), which is calculated by dividing the total number of citations (TC) by the total number of publications (TP). USA ranked first with 38.78, followed by Italy (34.42) and Australia (32.22). The h-index was initially referred to as a simple quantitative indicator, defined as researchers who have published at least h articles and have been cited h times. To some extent, this reflects the research achievements of researchers.[97] Later, academic groups or institutions,[98] journals[99] and countries[100] also used the h-index to measure their collective research achievements.[101] As shown in Table 1, USA ranked first with an h-index of 99 in this field. China and India followed closely behind, with h-indices of 92 and 83, respectively. The top three countries had significantly higher h indices than other countries did. Taking all the parameters into consideration, USA ranked first with an extremely high h-index and ACPP. China and India also had relatively high h-indices but only ranked in the upper middle range of the ACPP. However, given that their publication counts far surpassed those of other countries, publications from the USA, China, and India demonstrated the best average performance.

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Table 1 The Top 20 Most Productive Countries/Regions in the Nanoemulsions Field

RANK	Country	TP	TC	h-Index	ACPP	nCC	SP(%)	Region
1	China	1839	48,358	92	26.30	63	30.01	Asia
2	USA	1268	49,170	99	38.78	65	55.20	North America
3	India	1248	36,429	83	29.19	68	28.34	Asia
4	Brazil	862	17,237	56	20.00	43	24.44	South America
5	Iran	621	18,397	68	29.62	55	30.11	Asia
6	Saudi Arabia	582	14,998	63	25.77	54	75.08	Asia
7	Egypt	463	8650	46	18.68	49	54.06	Africa
8	Spain	370	11,166	53	30.18	59	58.43	Europe
9	South Korea	332	9133	48	27.51	35	32.37	Asia
10	Italy	296	10,187	54	34.42	52	53.09	Europe
11	France	282	6790	44	24.08	57	56.49	Europe
12	Malaysia	269	7119	46	26.46	44	48.78	Asia
13	UK	224	5942	42	26.53	52	75.62	Europe
14	Germany	216	4906	37	22.71	46	57.07	Europe
15	Portugal	189	5870	42	31.06	40	64.09	Europe
16	Canada	170	5410	41	31.82	35	68.55	North America
17	Australia	170	5477	42	32.22	42	70.75	Oceania
18	Japan	157	2758	29	17.57	32	53.52	Asia
19	Pakistan	155	4093	37	26.41	45	80.71	Asia
20	Mexico	151	3370	32	22.32	28	44.22	North America

Abbreviations: TP, total papers; TC, total citations; ACPP, average citations per publication; nCC, number of cooperative countries; SMCP, share of multinational cooperation publications.

Country/Region Cooperation

In the DDA software, if an article is coauthored by two or more countries' institutions, it is defined as an outcome of international collaboration.[102] The existence of affiliations between research institutions with international collaborations was not considered. Among the top 20 productive countries, Pakistan ranked first, with a cooperation rate of 80.71%, followed by the UK (75.62%) and Saudi Arabia (75.08%). In general, European countries have higher rates of international collaboration, whereas Asian countries, with the exceptions of Pakistan and Saudi Arabia, generally have lower rates of collaboration. In addition, although the number and level of publications in China and India are relatively high, their degree of international cooperation is low.

An academic cooperation network diagram of the top 20 contributing countries was constructed via DDA software (Figure 2). DDA software draws network diagrams on the basis of the co-occurrence matrix. The size of a circle is related to the country's relative contribution, and the lines between circles represent cooperation among countries. The thickness of the lines represents the frequency of cooperation. The results demonstrate that nine of the twenty countries have cooperation with other 18 countries, and seven countries have cooperation with all of the other nineteen countries, while Portugal and Australia have cooperation with only 16 countries, Malaysia with 15 countries, and Mexico with 14 countries (all the cooperation is limited to the top 20 contributing countries, cooperation with countries other than the top 20 is not included), and according to the thickness of the lines, it can be seen that cooperation between China and the United States is the most frequent, and Saudi Arabia has a close frequency of cooperation with other countries.

Contributions of the Most Productive Institutions

The total number of research institutions that have conducted research on nanoemulsions is 5067, and the top 20 research institutions were defined (Table 2). Among the top 20 institutions, four are from Brazil; three each from Saudi Arabia, Iran and China; two each from Egypt and Portugal; and one each from USA, India and Malaysia. In terms of research volume, the University of Massachusetts ranked first, with 275 publications, far exceeding those of other research institutions. This was followed by King Abdulaziz University (187) and Islamic Azad University (178). Among them,

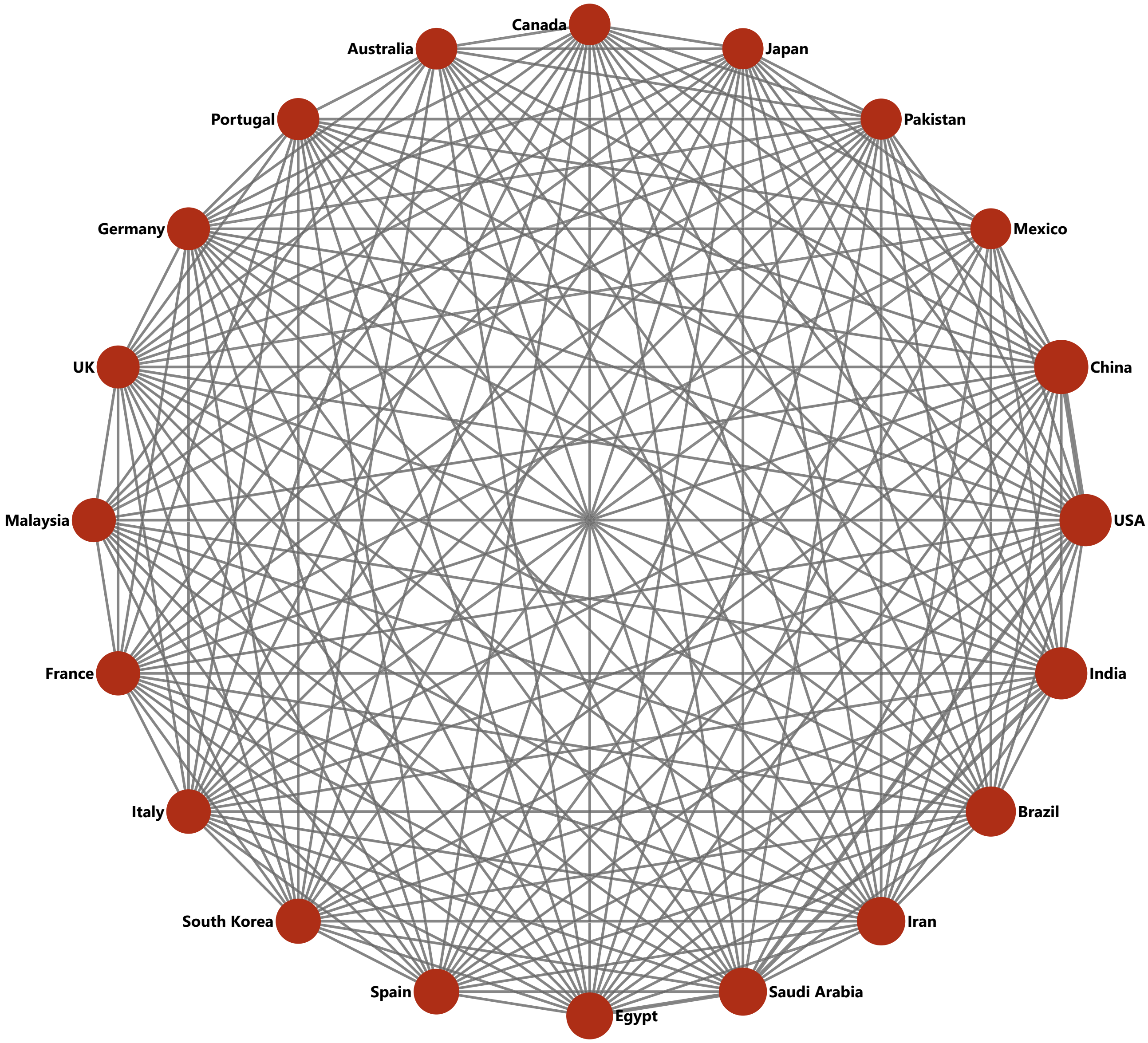

Figure 2 Collaboration matrix map of the top 20 most productive countries/regions.

Gorgan Univ Agr Sci & Nat Resource had the best ACPP, with a score of 65.85, followed by the University of Massachusetts (65.25) and Jiangnan University (41.91). The University of Massachusetts in USA was at the top of all institutions with the most publications (275), the highest ACPP (65.25), and the highest h-index (76). It also contributed significantly more than other countries did.

Table 2 The Top 20 Most Productive Institutions in the Nanoemulsions Field From 2013–2023

RANK	Institution	TP	TC	ACPP	h-Index	SMCP (%)	Country/Region
1	Massachusetts Univ	275	17,945	65.25	76	74.26	USA/North America
2	King Abdulaziz Univ	187	7657	40.95	48	81.42	Saudi Arabia/Asia
3	Islamic Azad Univ	178	3695	20.76	32	24.85	Iran/Asia
4	King Saud Univ	158	2753	17.42	29	60.00	Saudi Arabia/Asia
5	Univ Sao Paulo	157	3907	24.89	33	28.48	Brazil/South America

(*Continued*)

Table 2 (Continued).

RANK	Institution	TP	TC	ACPP	h-Index	SMCP (%)	Country/Region
6	Univ Fed Rio Grande do Sul	124	2737	22.07	32	17.53	Brazil/South America
7	Jamia Hamdard	120	3685	30.71	40	54.70	India/Asia
8	Univ Putra Malaysia	120	2770	23.08	32	29.82	Malaysia/Asia
9	Jiangnan Univ	115	4820	41.91	42	60.19	China/Asia
10	National Research Centre	112	1929	17.22	26	32.35	Egypt/Africa
11	Univ Fed Rio de Janeiro	105	1811	17.25	23	13.59	Brazil/South America
12	Cairo Univ	86	1663	19.34	22	30.49	Egypt/Africa
13	Gorgan Univ Agr Sci & Nat Resource	71	4675	65.85	35	38.37	Iran/Asia
14	Univ Tehran Med Sci	71	1771	24.94	24	20.00	Iran/Asia
15	Prince Sattam Bin Abdulaziz Univ	70	849	12.13	14	64.71	Saudi Arabia/Asia
16	Univ Barcelona	65	1965	30.23	24	25.81	Spain/Europe
17	Zhejiang Univ	65	2206	33.94	29	31.70	China/Asia
18	South China Univ Technol	63	2435	38.65	23	36.84	China/Asia
19	Minho Univ	62	2196	35.42	26	66.67	Portugal/Europe
20	Sao Paulo State Univ	60	1609	26.82	23	76.70	Brazil/South America
21	Univ Porto	60	1509	25.15	25	98.30	Portugal/Europe

Abbreviations: TP, total papers; TC, total citations; ACPP, average citations per publication; nCC, number of cooperative countries; SMCP, share of multinational cooperation publications.

The collaboration network among the top 15 institutions with the most contributions from 2013–2014 is illustrated (Figure 3). This collaborative network provides an intuitive perspective of cooperation between different institutions, which can help identify more beneficial collaborations. The number of publications is listed near the name of each institution and yellow cross points between institutions indicate cooperation with other research institutions. The yellow

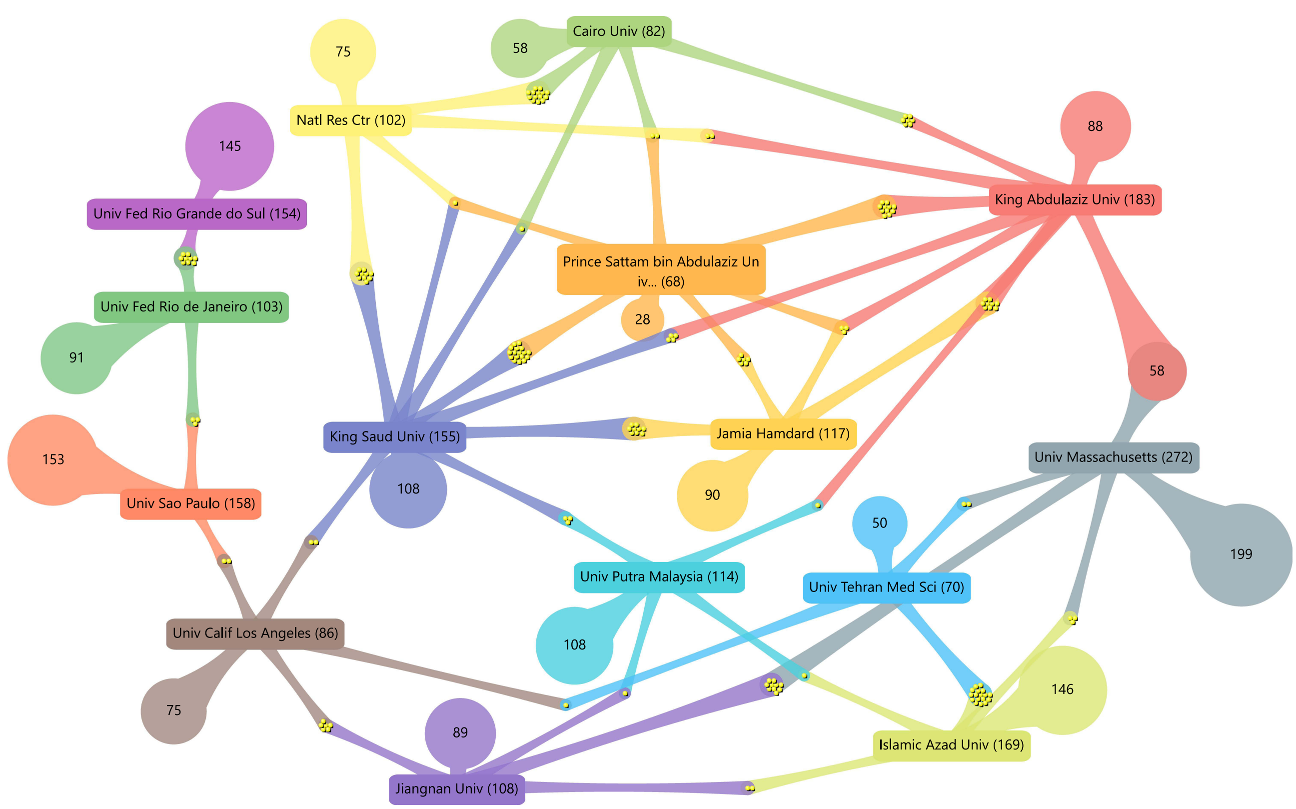

Figure 3 DDA cluster map of the cooperation of the top 15 institutions.

dots indicate the outputs and intensity of collaboration among institutions. The node data without intersections represent the number of publications published by the research institution, which may be independent research or collaboration with other institutions except the top 15. That King Abdulaziz Univ has built the largest collaborative network, followed by King Saud Univ and Prince Sattam bin Abdulaziz Univ (Figure 3). In terms of the number of collaborations, University of Massachusetts and King Abdulaziz Univ had the highest collaboration counts, with 59 articles, followed by Islamic Univ and Tehran Med sci Univ, as well as King Saud Univ and Prince Sattam bin Abdulaziz Univ. In addition, research in the field of nanoemulsions by Sao Paulo Univ, Fed Rio Grande do Sul Univ and Fed Rio de Janeiro Univ is relatively independent.

Contributions to Leading Research Fields

The analysis of research fields indicates the application direction of nanoemulsions. Research on nanoemulsions covered 87 different research fields, and the 20 most productive research fields with the highest number of publications are summarized (Table 3). "Chemistry" ranked first with 2885 articles, followed by "Pharmacology and Pharmacy" (2138) and "Food Science and Technology" (1952), which far surpassed other research fields in terms of the number of publications. The top three research fields in the ACPP ranking are "acoustics" (48.81), "nutrition" (39.12), and "food science and technology" (35.13). The literature in the field of acoustic research is related mainly to the preparation of nanoemulsions via ultrasonic emulsification. For example, Ghosh et al used ultrasonic emulsification to prepare basil oil nanoemulsions and characterized their antibacterial activity.[103]

A bubble chart of the 20 most productive nanoemulsions research fields is shown (Figure 4). The bubble chart depicts the growth tendency of research fields over time through horizontal changes in bubble size in three dimensions: research field, publication year, and number of publications. The vertical change in bubble size and the number within the bubbles represent the number of publications in various research fields for that particular year. Research achievements in most related fields are growing annually, with the number of research papers in environmental science and ecology increasing from 1 in 2013 to 34 in 2023, a 33-fold increase, indicating that breakthroughs have been made in this field, mainly due to extensive research on nanoemulsions pesticides.[104]

Table 3 Contributions of the Top 20 Research Areas in the Field of Nanoemulsions

RANK	Research Area	TP	TC	ACPP	h-Index
1	Chemistry	2885	90,174	31.26	118
2	Pharmacology Pharmacy	2138	51,798	24.23	88
3	Food Science Technology	1952	68,574	35.13	112
4	Material Science	1004	24,434	24.34	68
5	Science Technology Other Topics	886	23,116	26.09	70
6	Biochemistry Molecular Biology	724	17,393	24.02	63
7	Engineering	695	15,492	22.29	62
8	Physics	491	11,349	23.11	50
9	Polymer Science	480	12,888	26.85	60
10	Nutrition Dietetics	357	13,967	39.12	64
11	Agricultural	288	8251	28.65	51
12	Biotechnology Applied Microbiology	271	6946	25.63	40
13	Research Experimental medicine	228	6368	27.93	45
14	Biophysics	193	5542	28.72	43
15	Energy Fuels	140	4607	32.91	37
16	Environmental Science and Ecology	128	2948	23.03	30
17	Microbiology	115	3581	31.14	31
18	Acoustics	90	4393	48.81	39
19	Immunology	80	2471	30.89	25
20	Oncology	76	2447	32.20	23

Abbreviations: TP, total papers; TC, total citations; ACPP, average citations per publication.

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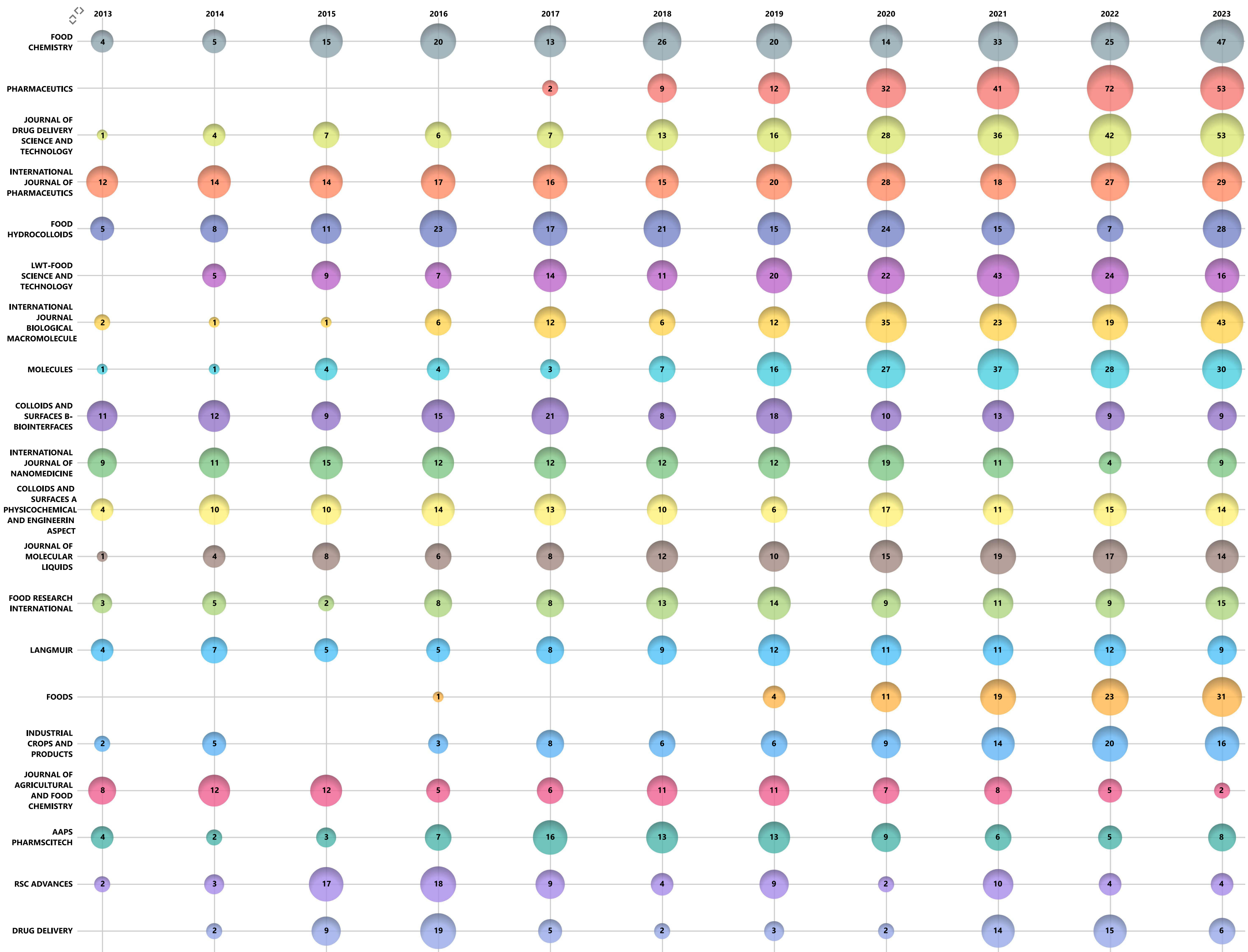

Figure 4 Bubble chart of the top 20 nanoemulsions research areas by year.

The differences in research directions between 2013–2023 and 2021–2023 were compared (Table 4). Except for the fact that most research directions have maintained their publication numbers, "Environmental Science and Ecology" has seen a significant increase in its ranking. In addition, "Plant Sciences" and "Entomology" have entered the top 20 research directions over the past three years.

Main Contributing Journals

Research on the primary contributing journals can help researchers of nanoemulsions more clearly decide which journal is the best choice for submission of their reports. From 2013 to 2023, a total of 1211 journals published 8561 papers related to nanoemulsions, and the total number of papers in the top 20 journals was defined (Table 5). Food Chem. ranked first with 222 papers, followed by Pharmaceutics (221, J). Drug Delivery Sci. and Technol. (213), and Int J. Pharmaceutics (210). With respect to total citations (TCs), Food Hydrocolloids was cited 11,934 times in the past decade in nanoemulsions research, ranking first, followed by Food Chem. (10,650) and Int. J. Pharmaceutics (6696). For the ACPP, Food Hydrocolloids still ranked first at 68.19 times, followed by J Agric. and Food Chem. (52.06) and Food Chem (47.97). A journal's impact factor is calculated by dividing the total number of citations to all publications in that journal over the previous two years by the number of publications.[105] As shown in Table 5, the ACPP of all journals' papers on nanoemulsions were greater than their own IF, which fully reflects researchers' strong interest in the research of nanoemulsions. With respect to the impact factor, Food Hydrocolloids had the highest impact factor of 10.7 in 2022, followed by Food Chem. (8.8) and Int J. of Biol. Macromolecules (8.2), Food Res. Int. (8.1) and Int J. Nanomed. (8.0).

A bubble chart of the top 20 journals publishing papers on nanoemulsions is shown (Figure 5). The bubble chart reveals that Pharmaceutics did not publish any articles before 2017, with only 2 articles published in 2017, but reached 72 articles in 2022, ranking second among all the journals and growing 35-fold. Int. J. Biol. Macromolecules had only 2 articles in 2013 but reached 43 articles in 2023, a 20-fold increase. Drug Delivery reached a peak of 19 articles published in 2016. Most journals reported a peak in articles on nanoemulsions research from 2021–2023.

Table 4 Comparison of the Nanoemulsions Research Areas in 2013–2023 and 2021–2023

Research Area	2013–2023 TP		2021–2023 TP	Proportion (%)
Chemistry	2885	Chemistry	1121	38.86
Pharmacology Pharmacy	2138	Pharmacology Pharmacy	882	41.25
Food Science Technology	1952	Food Science Technology	881	45.13
Material Science	1004	Material Science	389	38.75
Science Technology Other Topics	886	Biochemistry Molecular Biology	375	51.80
Biochemistry Molecular Biology	724	Science Technology Other Topics	334	37.70
Engineering	695	Engineering	271	38.99
Physics	491	Polymer Science	242	50.42
Polymer Science	480	Physics	207	42.16
Nutrition Dietetics	357	Nutrition Dietetics	174	48.74
Agricultural	288	Agricultural	130	45.14
Biotechnology Applied Microbiology	271	Biotechnology Applied Microbiology	105	38.75
Research Experimental medicine	228	Research Experimental medicine	88	38.60
Biophysics	193	Environmental Science and Ecology	70	54.69
Energy Fuels	140	Energy Fuels	64	45.71
Environmental Science and Ecology	128	Microbiology	58	50.43
Microbiology	115	Biophysics	53	27.46
Acoustics	90	Plant Science	42	64.62
Immunology	80	Entomology	32	57.14
Oncology	76	Oncology	28	36.84

Abbreviation: TP, total papers.

Table 5 Top 20 Journals Publishing Studies in Nanoemulsions

RANK	Journal Title	TP	TC	ACPP	If (2022)
1	Food Chem.	222	10,650	47.97	8.8
2	Pharmaceutics	221	4122	18.65	5.4
3	J. Drug Delivery Sci. Technol.	213	3114	14.62	5
4	Int. J. Pharm.	210	6696	31.89	5.8
5	Food Hydrocolloids	175	11,934	68.19	10.7
6	LWT Food Sci. Technol.	171	5774	33.77	6
7	Int. J. Biol. Macromol.	160	5712	35.7	8.2
8	Molecules	158	3111	19.69	4.6
9	Colloids Surf., B	135	4371	32.38	5.8
10	Int. J. Nanomed.	126	4418	35.06	8
11	Colloids and Surf., A	124	2745	22.14	5.2
12	J. Mol. Liq.	114	1993	17.48	6
13	Food Res. Int.	97	3217	33.16	8.1
14	Langmuir	93	1661	17.86	3.9
15	Foods	89	1294	14.54	5.2
16	Ind. Crops Prod.	89	2035	22.87	5.9
17	J. Agric. Food Chem.	87	4529	52.06	6.1
18	AAPS Pharmscitech	86	1708	19.86	3.3
19	RSC Advances	82	1723	21.01	3.9
20	Drug Delivery	77	2572	33.4	6

Abbreviations: TP, total papers; TC, total citations; ACPP, average citations per publication; IF, impact factor.

Contributions of Leading Authors

The study of the contributions of leading authors can promote exchanges and collaborations among scholars interested in nanoemulsions research. Within our analysis scope, 29,769 authors contributed to nanoemulsions research, and the 20 most productive authors by number of publications are displayed (Table 6. Among these 20 authors, 6 are from Brazil, 4 each are from Saudi Arabia and Spain, 2 each are from India and the USA, and 1 each is from France, Iran, and Malaysia. Among the 4 authors from Saudi Arabia, 3 are from King Saud University, and 2 each are from Massachusetts Univ (USA), Federal do Rio Grande do Sul Univ (Brazil), Lleida Univ (Spain), Jamia Hamdard Univ (India), Sao Paulo Univ (Brazil), and Federal do Amapa Univ (Brazil).

McClements, DJ ranked first, with 248 publications, far exceeding those of other scholars, indicating his significant contribution to this research area. Teixeira, HF ranked second with 71 publications, and Shakeel, F ranked third with 54 publications. In terms of the ACPP, Trujillo, Laura Salvia ranked first with 89.56, followed by Jafari, SM (79.98), McClements, DJ (70.86), and Martin-Belloso, O (68.79). With respect to the h-index, McClements, DJ ranked first with a score of 76, far surpassing other scholars, followed by Jafari, SM (35), Xiao, H (29), Ali, J (24), Baboota, Sanjula (24), and Salvia-Trujillo, L (24). There are two limitations in comparing the h-indices of scholars.[106] First, the h-index only increases or remains constant over time, so it cannot indicate whether a scholar is still active in their academic career. Second, older scholars who entered the academic field earlier have an advantage in the h-index compared with younger scholars.

Research Hotspots and Tendencies

To better understand the research hotspots and tendencies of nanoemulsions, the author keywords, hot papers, and highly cited papers from 8561 articles were analyzed. These research topics were sourced from databases such as the SCI-E and SSCI of the Web of Science.[107] ESI hot papers were defined as papers published globally in the last 2 months with high citation frequency. Highly cited papers were defined as research in the same discipline that ranks in the top 1% of citation frequency within the 10-year range included in the ESI.

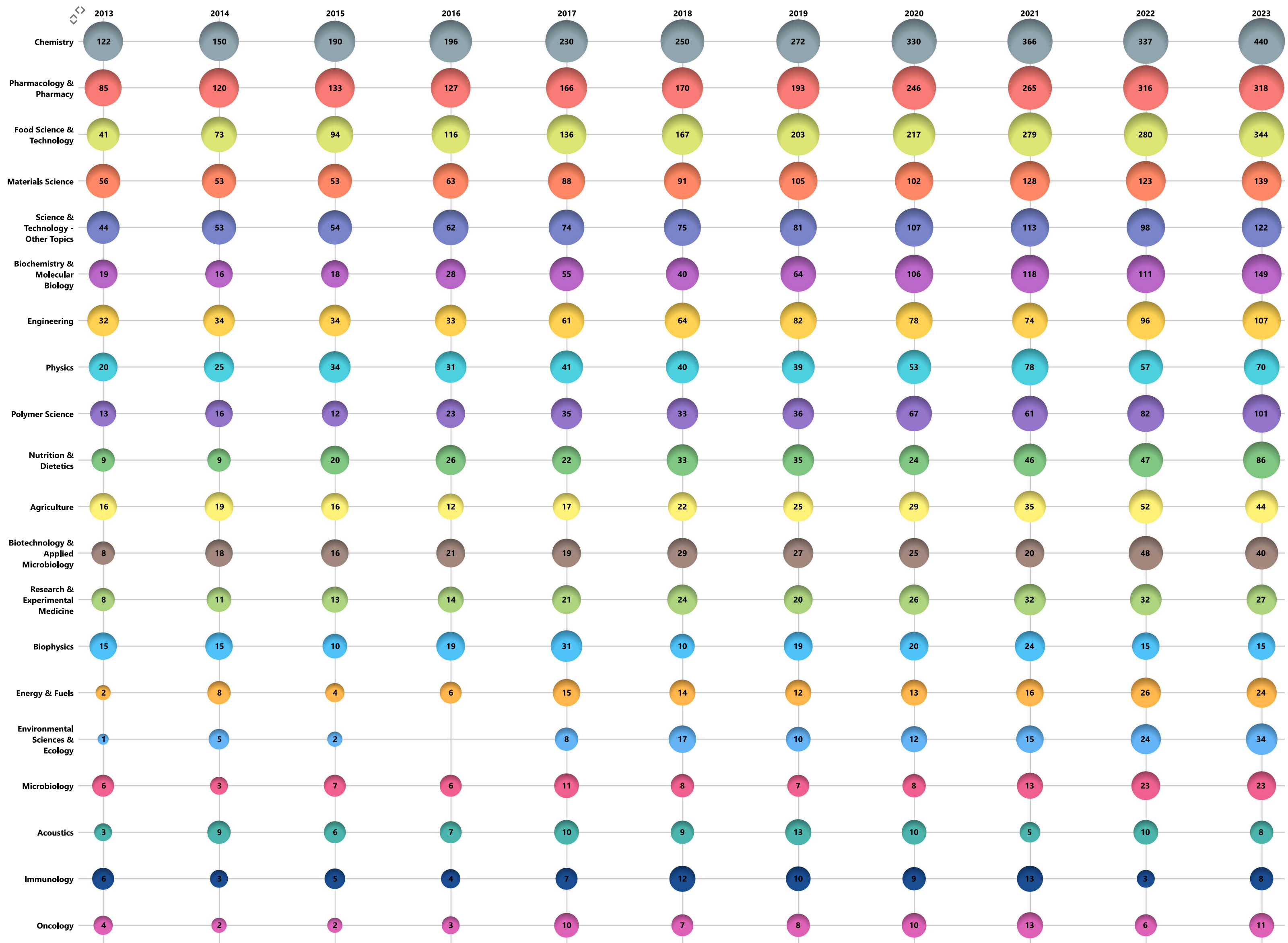

Figure 5 Bubble chart of the top 20 journals publishing papers on nanoemulsions.

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Table 6 Contributions of the Top 20 Authors in Nanoemulsions Research

RANK	Author	TP	TC	ACPP	h-Index	Institution	Country/Region
1	McClements, David Julian	248	17,574	70.86	76	Univ of Massachusetts	USA/North America
2	Teixeira, Helder Ferreira	71	1515	21.34	22	Univ Federal do Rio Grande do Sul	Brazil/South America
3	Jafari, Seid Mandi	54	4319	79.98	35	Gorgan Univ of Agricultural Sciences and Natural Resources	Iran/Asia
4	Shakeel, Faiyaz	50	1040	20.8	18	King Saud Univ	Saudi Arabia/Asia
5	Ali, Javed	48	1683	35.06	24	King Saud Univ	Saudi Arabia/Asia
6	Martin-Belloso, Olga	48	3302	68.79	23	Univ of Lleida	Spain/Europe
7	Anton, Nicolas	44	1020	23.18	19	Univ de Strasbourg	France/Europe
8	Baboota, Sanjula	42	1376	32.76	24	Jamia Hamdard Univ	India/Asia
9	Basri, Mahiran	42	1016	24.19	21	Univ Putra Malaysia	Malaysia/Asia
10	Maranhao, Raul Cavalcante	40	565	14.13	15	Univ of Sao Paulo	Brazil/South America
11	Koester, Leticia Scherer	39	940	24.1	19	Univ Federal do Rio Grande do Sul	Brazil/South America
12	Salvia-Trujillo, Laura	39	3493	89.56	24	Univ of Lleida	Spain/Europe
13	Solans, Conxita	39	1077	27.62	15	CIBERBBN	Spain/Europe
14	Fernandes, Caio pinho	38	793	20.87	17	Univ Federal do Amapa	Brazil/South America
15	Xiao, Hang	38	2142	56.37	29	Univ of Massachusetts	USA/North America
16	Tavares Carvalho, Jose Carlos	37	890	24.05	17	Univ Federal do Amapa	Brazil/South America
17	Ahmad, Farhan Jalees	35	1267	36.2	23	Jamia Hamdard Univ	India/Asia
18	Hosny, Khaled Mohamed	35	528	15.09	15	King Abdulaziz Univ	Saudi Arabia/Asia
19	Haq, Nazrul	32	447	13.97	13	King Saud Univ	Saudi Arabia/Asia
20	Tedesco, Antonio Claudio	31	614	19.81	17	Univ of Sao Paulo	Brazil/South America

Abbreviations: TP, total papers; TC, total citations; ACPP, average citations per publication.

Author Keyword Analysis

Author keywords can provide valuable information on research-related topics, making them a focus of widespread attention among scholars.[108] A total of 14,310 author keywords were obtained by representing keywords with similar meanings in a unified term. Notably, publications without author keywords were not included in the statistics. Among the 8561 articles, the 30 most common author keywords are displayed in a bubble chart (Figure 6). The top 30 keywords comprise several main categories, including terms representing nanoscale particles: "nanoemulsions", "nanoparticles", "solid lipid nanoparticles", "liposomes", "nanocarriers", and "nanomedicine." In addition, keywords such as "essential oil", "curcumin", "chitosan", and "beta-carotene" indicate common application areas and encapsulating materials of nanoemulsions. Furthermore, research on the properties of nanoemulsions, mainly related to "bioavailability", "stability", "antioxidant activity", "antimicrobial activity", "cytotoxicity", and "antibacterial activity", is also prominent. Common preparation methods for nanoemulsions, such as "ultrasonication", "high-pressure homogenization", and "microfluidization", also have high frequencies. As the third highest-frequency keyword, "essential oil" had fewer publications before 2016, with only 9 articles in 2016. However, in 2017, 23 articles were published, and the trend continued to grow, reaching a peak of 93 articles in 2022. This growth is attributed mainly to the extensive research and application of nanoemulsions containing essential oils in the food industry because of their antimicrobial and antioxidant characteristics. For example, Erfani et al prepared a nanoemulsions containing cinnamon essential oil encapsulated in beta-cyclodextrin and sodium caseinate, resulting in a longer storage time.[109] Restrepo et al prepared nanoemulsions containing lemongrass and rosemary essential oils incorporated into edible films, which were shown to increase the breathability, transparency, and extensibility of the films.[110] Many essential oils have been formulated into nanoemulsions, such as lemon oil,[111] lavender oil,[112] marigold oil[113] and patchouli leaf oil,[114] which exhibit superior performance.

In the pharmaceutical industry, research on nanoemulsions in the drug delivery field has been increasing annually. For example, Abdulaal et al reported the preparation and formulation optimization of sodium alendronate nanoemulsions for in situ injection for the treatment of osteoporosis in 2023. Compared with traditional oral dosage forms, the phase separation injectable sodium alendronate nanoemulsions exhibited sustained and controllable drug release.[115] El Makawy et al prepared quinoa oil-alginate nanoemulsions showing anticancer activity against breast cancer, inhibiting the further development of breast cancer.[116]

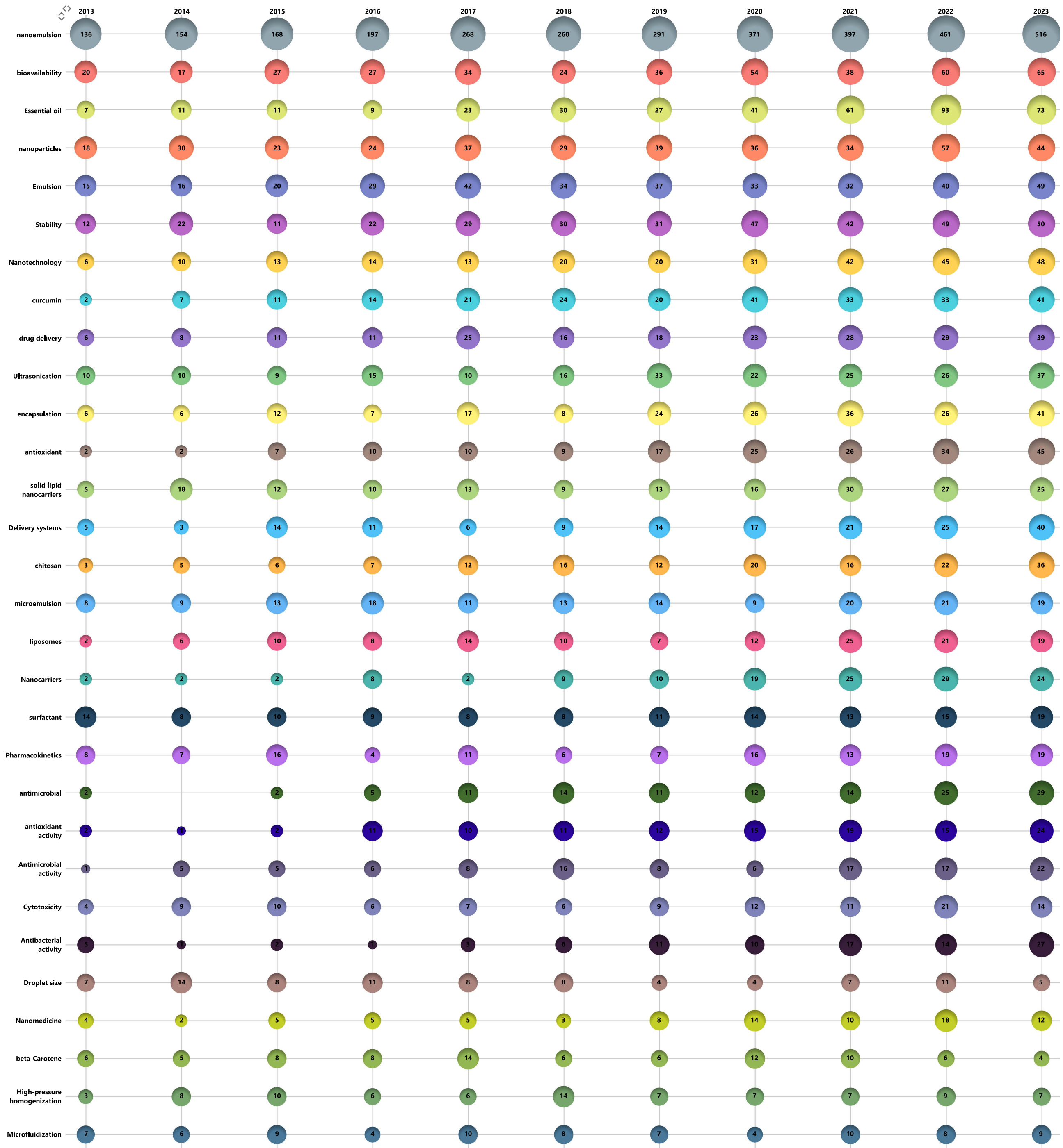

Figure 6 Bubble chart of the top 30 author keywords by year.

According to the keyword "curcumin", curcumin is commonly encapsulated in nanoemulsions. Curcumin has multiple pharmacological actions, such as anticancer, anti-inflammatory, and antioxidant effects.[117] It is also an important natural edible pigment in the food industry that is safe and nontoxic. It has wide applications in many industrial fields, such as medicine,[118] textile dyeing,[119] and feed.[120] Nonetheless, owing to its poor water solubility, chemical stability, and oral bioavailability,[121] its application is often limited. Studies have shown that encapsulating curcumin in nanoemulsions can improve its dispersibility and chemical stability due to the extremely small droplet size, providing more possibilities for drug delivery routes, regulating its release, promoting interaction with biological membranes, and improving bioavailability[122] to promote its application. Ghanimatda et al prepared a curcumin nanoemulsions that showed therapeutic effects on cystic hydatidosis.[123] Ganta et al encapsulated paclitaxel and curcumin in a nanoemulsions containing linseed oil to treat ovarian cancer, which effectively enhanced the apoptotic response.[124] Yu et al prepared a curcumin nanoemulsions using a curcumin organic gel as the oil phase, which resulted in a significant increase in oral bioavailability and achieved the oral delivery of poorly soluble nutrients.[125]

The top five keywords used in each of the 20 countries that have contributed the most to the nanoemulsions field are displayed (Table 7). Unsurprisingly, "nanoemulsions", "nanoparticles", "essential oils" and "bioavailability" are the most commonly used keywords in these countries. In addition to the use of nanoemulsions and emulsion as key words, among the top three countries contributing to the ranking, China has primarily studied stability, bioavailability and curcumin; USA has studied nanoparticles, bioavailability and stability; and India has studied bioavailability, nanoparticles, nanogels and essential oils. Additionally, many studies have been conducted on the preparation technology of nanoemulsions in Malaysia, as reflected by the use of "response surface methodology" and "high-pressure homogenization", such as for the preparation of aspirin nanoemulsions via response surface methodology[126] and the preparation of polycarboxylate nanoemulsions via high-pressure homogenization.[127] Germany has conducted more research on lipid nanoparticles, and two of the top five keywords used are related to lipid nanoparticles; comparative studies between nanoemulsions and lipid nanoparticles have also been conducted.[128] In addition, "inflammation" is also the only keyword that appeared in the top five keywords of Germany among the 20 countries, reflecting the importance attached to it.[129]

The Sankey diagram shows the flow relationships between the top ten institutions and the ten key words related to nanoemulsions (Figure 7). The results show that most of the top ten institutions have some knowledge of these ten key words, and most research has focused on key words related to nanoemulsions such as "drug delivery", "cytotoxicity", "curcumin", "carotene", "stability" and "antioxidants". The Univ Sao Paulo, Univ Putra Malaysia and Univ Fed Rio Grande do Sul focused on drug delivery research, Natl Res Ctr and King Saud Univ focused on cytotoxicity research, Jamia Hamdard and King Abdulaziz Univ focused on curcumin research, Jiangnan Univ focused on β-carotene research, Massachusetts Univ focused on stability and β-carotene research, and Islamic Azad Univ focused on antioxidant research.

Table 7 Top 5 Most Used Author Keywords by the Top 20 Most Productive Countries

Country	Top 5 highly Used Author Keywords
China	Nanoemulsions, stability, bioavailability, emulsion, curcumin
USA	Nanoemulsions, emulsion, nanoparticles, bioavailability, stability
India	Nanoemulsions, bioavailability, nanoparticles, nanoemulgel, essential oil
Brazil	Nanoemulsions, nanotechnology, nanoparticles, essential oil, drug delivery
Iran	Nanoemulsions, essential oil, encapsulation, bioavailability, chitosan
Saudi Arabia	Nanoemulsions, essential oil, nanoemulgel, bioavailability, optimization
Egypt	Nanoemulsions, essential oil, bioavailability, optimization, antimicrobial
Spain	Nanoemulsions, essential oil, emulsion, microfluidization, encapsulation
South Korea	Nanoemulsions, emulsion, stability, nanoparticles, chitosan,
Italy	Nanoemulsions, essential oil, nanoparticles, curcumin, chitosan
Malaysia	Nanoemulsions, response surface methodology, nanoparticles, high-pressure homogenization, antioxidant
France	Nanoemulsions, emulsion, nanoparticles, essential oil, curcumin
UK	Nanoemulsions, emulsion, nanoparticles, drug delivery, bioavailability
Germany	Nanoemulsions, lipid nanoparticles, solid lipid nanoparticles, drug delivery, inflammation
Portugal	Nanoemulsions, nanoparticles, antioxidant, nanotechnology, nanostructured lipid carriers
Canada	Nanoemulsions, stability, emulsion, bioavailability, drug delivery
Australia	Nanoemulsions, drug delivery, nanoparticles, bioavailability, essential oil
Mexico	Nanoemulsions, essential oil, curcumin, antioxidant, emulsion
Japan	Nanoemulsions, nanoparticles, stability, emulsion, essential oil
Pakistan	Nanoemulsions, bioaccesssibility, bioavailability, chitosan, nanoparticles

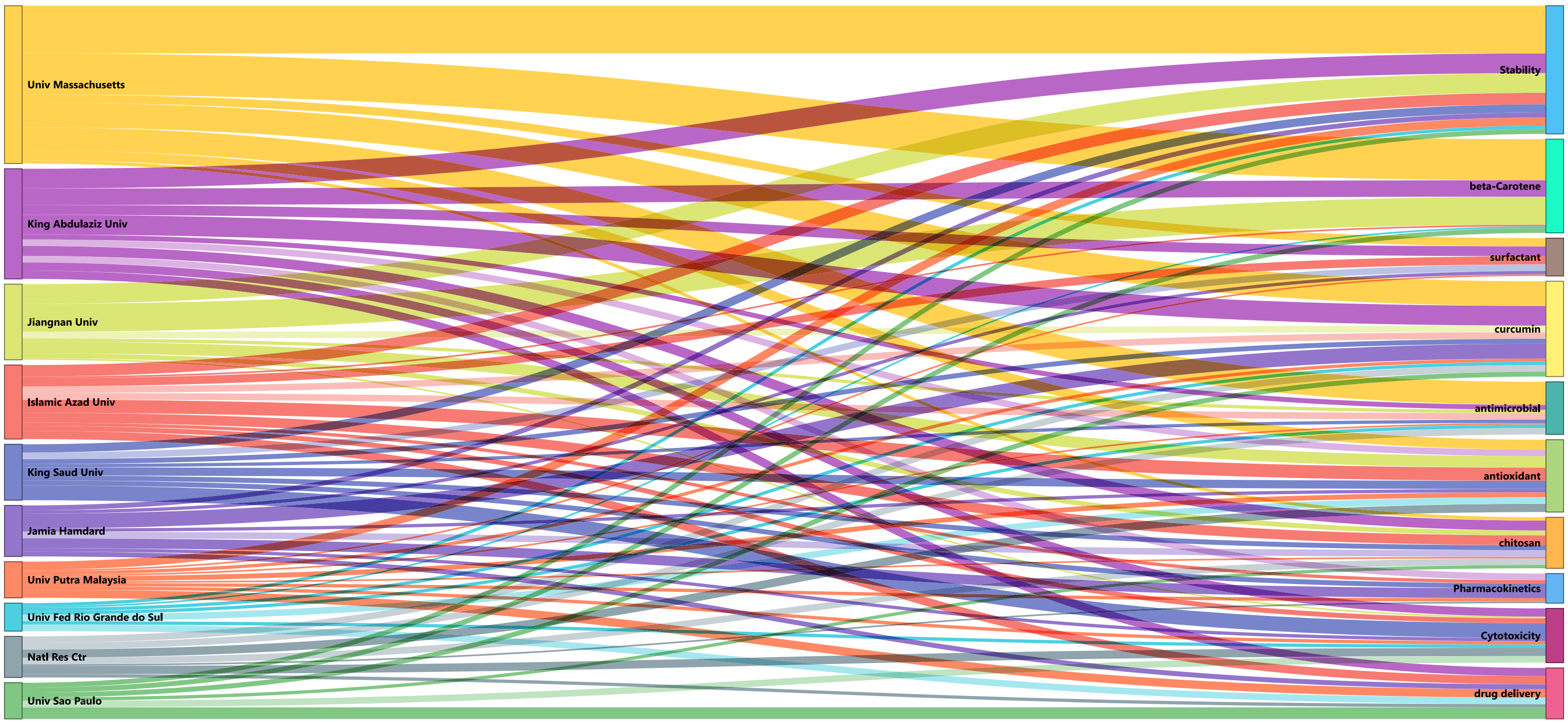

Figure 7 Sankey chart of the top 10 institutions.

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Analysis of Hot Research Papers

The number of citations is an important indicator reflecting the impact of a study. According to our definition of hot papers, six such papers were identified and presented (Table 8). Notably, this article took the top-ranked authoritative institution as a representative and displays corresponding institutions. Among the six articles, four are review articles, and two are research articles. Sneha et al introduced the preparation of nanoemulsions and their progress in food applications.[130] Zhang et al reviewed the use of lipid carriers for mRNA delivery, including the application of nanoemulsions in mRNA delivery.[131] Karimi-Maleh et al introduced research on Mof pesticides in sustainable agriculture and reduction of environmental hazards.[132] Nanopesticides overcome the shortcomings of traditional pesticides and have become a promising alternative. Phatale et al researched advanced drug delivery methods to overcome the skin barrier.[133] Nanoemulsions constitute a new strategy for effective transdermal drug delivery. Haddadzadegan et al reviewed the oral delivery technology of therapeutic peptides and proteins, such as oil-in-water nanoemulsions, using lipid-based nanocarriers.[134] Philip et al conducted magnetic nanofluid research in which a nanoemulsions was used as a model system for magnetic nanofluids and reviewed its applications in various aspects.[135] The above studies focused on the application of nanoemulsions in the drug delivery, food, agriculture and environmental industries. In terms of the scholars' countries, three are from India, two are from China, and one is from Australia.

Research Analysis of Highly Cited Papers

The top 20 cited articles from the 8561 nanodispersion articles collected in this study were analyzed, and the specific publication information was collected (Table 9). Among the 20 articles, 11 were review papers and 9 were research papers. USA and India each contributed six papers, significantly surpassing other countries. China contributed three papers, Spain two, and the Netherlands, Australia, and Italy one each. Gupta et al summarized the formation, characteristics and applications of nanoemulsions, and had the highest total number of citations.[66] The article with the highest average number of citations per year was published in Nature Communications in 2018 by Wan et al, who provided a simple method for preparing thin-film composite nanofiltration membranes with polyamide layers, which is highly important for seawater desalination and sewage treatment.[136]

Three of the 20 highly cited articles are related to nanopesticides. Kah et al conducted research on nanopesticides in 2014, mainly exploring formulations of related nanoemulsions.[145] In 2017, Prasad et al reported that nanotechnology can improve food quality and safety, such as the application of nanoemulsions to ice cream to improve its texture and uniformity and the ability to control the amount of pesticide sprayed and reduce the loss of nutrients during fertilization in agricultural fields.[146] Kumar, S. reported in 2019 that the nanoencapsulation of pesticides can result in controlled

Table 8 ESI Hot Citation Studies From 2013–2023

NO	Author	Title	TC	Journal	Institution, Country/Region	OPC
1	Sneha, K et al	Nanoemulsions: Techniques for the preparation and the recent advances in their food applications	66	Innovative Food Sci. Emerging Technol	Lovely Profess Univ (India/Asia)	None
2	Zhang, et al	Lipid carriers for mRNA delivery	20	Acta Pharm. sin. B	China Pharmaceutical Univ (China/Asia)	None
3	Karimi-Maleh et al	Mof-enabled pesticides as developing approach for sustainable agriculture and reducing environmental hazards	27	J. Ind. Eng. Chem.	Wenzhou Med Univ (Cina/Asia)	Lebanon; Iran
4	Phatale, V et al	Overcoming skin barriers through advanced transdermal drug delivery approaches	98	J. Controlled Release	Guwahati NIPER G (India/Asia)	None
5	Haddadzadegan, S et al	Oral delivery of therapeutic peptides and proteins: Technology landscape of lipid-based nanocarriers	134	Adv. Drug Delivery Rev.	Univ Innsbruck (Austria/Europe)	Iran
6	Phillip, J et al	Magnetic nanofluids(ferrofluids): recent advances, applications, challenges, and future direction	65	Adv. Colloid Interface Sci.	Indira Gandhi Ctr Atom Res (India/Asia)	None

Abbreviations: TC, total citations; TCY, total citations per year; OPC, other partner countries.

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Table 9 Top 20 Most Highly Cited ESI Publications From 2013–2023

NO	Author	Title	TC	TCY	Journal	Institution, Country/Region	OPC
1	Gupta, A et al	Nanoemulsions: formation, properties and applications	854	122	Soft Matter	MIT (USA/North America)	Netherlands
2	Singh, Y et al	Nanoemulsions: concepts, development and applications in drug delivery	742	123.7	J. Controlled Release	Cent Drug Res Inst (India/Asia)	None
3	Van Straten, D et al	Oncologic Photodynamic Therapy: Basic Principles, Current Clinical Status and Future Directions[137]	715	119.2	Cancers	Univ Utrecht (Netherlands/Europe)	None
4	Wang, ZY et al	Nanoparticle-templated nanofiltration membranes for ultrahigh performance desalination	673	134.6	Nat. Commun.	Chinese Acad sci (China/Asia)	USA
5	McClements, DJ et al	Improving emulsion formation, stability and performance using mixed emulsifiers: A review[138]	621	124.2	Adv. Colloid Interface Science	Univ Massachusetts (USA/North America)	Iran
6	Jaiswal, M et al	Nanoemulsions: an advanced mode of drug delivery system[139]	620	77.5	3 Biotech	Galgotias Univ (India/Asia)	None
7	Smith, DM et al	Applications of nanotechnology for immunology[140]	561	56.1	Nat. Rev. Immunol.	Univ of Michigan (USA/North America)	None
8	Ezhilarasi, PN et al	Nanoencapsulation Techniques for Food Bioactive Components: A Review[141]	535	53.5	Food Bioprocess Technol.	Cent Food Technol Res Inst (India/Asia)	None
9	Prasad, R et al	Nanotechnology in Sustainable Agriculture: Recent Developments, Challenges, and Perspectives	516	86	Front. Microbiol.	Amity Univ (India/Asia)	Hungary
10	Song, XJ et al	Ultrasound Triggered Tumor Oxygenation with Oxygen-Shuttle Nanoperfluorocarbon to Overcome Hypoxia-Associated Resistance in Cancer Therapies	495	70.7	Nano Lett.	Soochow Univ (China/Asia)	None
11	Anselmo, Ac et al	Elasticity of Nanoparticles Influences Their Blood Circulation, Phagocytosis, Endocytosis, and Targeting	468	58.5	ACS Nano	Univ Calif Santa Barbara (USA/North America)	None
12	Salvia-Trujillo, L et al	Influence of particle size on lipid digestion and β-carotene bioaccessibility in emulsions and nanoemulsions	465	46.5	Food Chem.	Univ Lleida (Spain/Europe)	USA
13	Kah, M et al	Nanopesticide research: Current trends and future priorities	434	48.2	Environ. Int.	Univ Vienna (Austria/Europe)	None
14	Acevedo-Fani, A et al	Edible films from essential-oil-loaded nanoemulsions: Physicochemical characterization and antimicrobial properties	431	53.9	Food Hydrocolloids	Univ Lleida (Spain/Europe)	None
15	Lu, Y et al	Polymeric micelles and alternative nanonized delivery vehicles for poorly soluble drugs	431	43.1	Int. J. Pharm.	Purdue Univ (USA/North America)	South Korea
16	Donsi, F et al	Essential oil nanoemulsions as antimicrobial agents in food	410	58.6	J. Biotechnol.	Univ Salerno (Italy/Europe)	None
17	Peng, L et al	Versatile Nanoemulsions Assembly Approach to Synthesize Functional Mesoporous Carbon Nanospheres with Tunable Pore Sizes and Architectures[142]	397	99.3	J. Am. Chem. Soc.	Fudan Univ (China/Asia)	None
18	Kharat, M et al	Physical and Chemical Stability of Curcumin in Aqueous Solutions and Emulsions: Impact of pH, Temperature, and Molecular Environment[143]	394	65.7	J. Agric. Food Chem.	Univ Massachusetts (USA/North America)	Saudi Arabia
19	Sari, TP et al	Preparation and characterization of nanoemulsions encapsulating curcumin[144]	376	47	Food Hydrocolloids	Natl Dairy Res Inst (India/Asia)	None
20	Kumar, S et al	Nano-based smart pesticide formulations: Emerging opportunities for agriculture	373	93.3	J. Controlled Release	Guru Jambheshwar Univ (India/Asia)	Italy, USA, South Korea

Abbreviations: TC, total citations; TCY, total citations per year; OPC, other partner countries.

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release characteristics, which can effectively improve the permeability, stability, and solubility of pesticides, and looked forward to the development of nanoemulsions pesticides.[147]

In terms of medical applications, in 2016, Song et al reported the good biocompatibility and high oxygen solubility of perfluorocarbons (PFCs), such as PFC nanoemulsions, as ultrasound-triggered tumor-specific oxygen delivery oxygen shuttles to regulate the hypoxic microenvironment of tumors.[148] Anselmo et al synthesized PEG hydrogel nanoparticles with adjustable elasticity via nanoemulsions technology in 2015 and determined the effects of the elasticity of the nanoparticles on their blood circulation, phagocytosis, endocytosis, and targeting.[149] Lu et al studied the use of polymeric micelles and alternative nanocarriers to solubilize poorly soluble drugs in 2013. For example, nanoemulsions can be administered in various ways, such as oral, ocular, sublingual, or intranasal, and are characterized by high drug loading and high bioavailability. The disadvantage of these methods is that they often lack stability and are prone to flocculation and coalescence.[150]

With respect to food applications, Salvia-Trujillo et al reported in 2013 the effects of the particle size of emulsions and nanoemulsions on lipid digestion and the accessibility of β-carotene, providing valuable knowledge for the development of carotenoid-based delivery for food and pharmaceutical applications.[151] Acevedo-Fani et al prepared nanoemulsions with thyme, lemongrass or sage oils as the dispersed phase and sodium alginate solution as the continuous phase by microfluidization to prepare edible films. The physicochemical and antibacterial properties were also characterized.[152]

The 20 highly cited articles not being mentioned are cited in Table 9.[137–144]

Discussion

The main goals of this bibliometric research were to determine the trends in the literature on nanoemulsions research; identify countries/regions, institutions, authors, author keywords, hot papers, and highly cited papers; and summarize the current status, hotspots, and changing tendencies of the nanoemulsions field. Nanoemulsions, as biphasic dispersed systems with droplet sizes at the nanoscale, provide a platform for dissolving poorly soluble drugs and various hydrophobic compounds, enabling the delivery of a variety of substances. They have found widespread applications in many industries and fields and have become among the more advanced carrier delivery systems in pharmaceutical, food, cosmetic, and agricultural products. On the basis of an extensive bibliometric analysis, this study aimed to provide more fertile ground for new topics in the technology and application of nanoemulsions.

Pharmaceutical Science

As an effective drug delivery system, extensive research has shown that, compared with other drug administration systems, nanoemulsions have better patient compliance and greater health benefits, effectively protecting the delivery of hydrophobic drugs and improving bioavailability. According to the keyword analysis, nanoemulsions are widely used as drug delivery systems for hydrophobic drugs, and research on their properties is the most prevalent, with a particular focus on studies of bioavailability, pharmacokinetics, and cytotoxicity when used as nanopharmaceuticals. Nanoemulsions can significantly improve drug release profiles and bioavailability when administered through different routes. The mechanism of their ability to increase bioavailability is due primarily to their lipid-based delivery system, which can increase the solubility and stability of lipophilic drugs. Their small size can also increase drug penetration and retention, especially when used as a transdermal drug delivery system.[153] For use of quercetin as an oral drug, Mahadev et al prepared a quercetin nanoemulsions via an ultrasound method, and the results revealed that the bioavailability and therapeutic effect on diabetes in diabetic rats were greatly improved.[154] In addition, researchers have prepared oral nanoemulsions forms of 5-fluorouracil,[155] piperine,[156] β-carotene,[157] and rutin.[158] Their successful development has improved the bioavailability of drugs. For use as a nasal drug delivery carrier, Diedrich et al prepared a chitosan-coated nanoemulsions containing luteolin for nasal administration to treat neuroblastoma. The results revealed that its permeability increased by a factor of 6, the pharmacokinetic evaluation half-life increased by a factor of 10, the biodistribution increased by a factor of 4.4, and the bioavailability increased.[159] Researchers commonly evaluate the pharmacokinetics and pharmacodynamics of drugs encapsulated in nanoemulsions. The main research topics include the in vivo half-life, biological distribution, area under the blood concentration-time curve and maximum drug concentration.[160] To explore the degree of improvement in bioavailability of nanoemulsions, these studies are indispensable. Extensive studies have shown that making drugs into nanoemulsions can reduce their cytotoxicity[161–163] because nanoemulsions are not only mild in formulation but also have slow release characteristics, a small droplet size and a high dispersion coefficient, which can reduce drug accumulation, thus alleviating the toxic side effects of drugs.

Given the impact of the novel coronavirus, the prevalence and mortality of the COVID-19 pandemic have increased significantly.[164,165] Owing to the increasing prevalence of bacteria resistant to natural or synthetic antibiotics,[166] infections caused by multidrug-resistant bacteria have become a serious public health problem. Antibiotic resistance has become a health issue of global concern. To some extent, conventional antibiotic treatment has been unable to meet people's antibacterial needs. Improving the delivery system of antibacterial drugs is an effective means to solve this problem. In recent years, interest in the antibacterial properties of nanoemulsions has increased. Whether it is a nanoemulsions encapsulating essential oils with antibacterial activity, the surfactant used in the preparation process, or the inherent antibacterial properties of the nanoemulsions, the main manifestation is the destruction of the lipid membrane of pathogens,[167] resulting in synergistic antibacterial effects and good therapeutic effects. The small spherical size of nanoemulsions droplets can prolong their retention at the lesion site and improve the antibacterial effect of drugs, and nanoemulsions antimicrobial therapy has good biocompatibility and spectral activity,[168] making it a promising carrier for COVID-19 treatment.[169–171] Moreover, the structure and function of nanoemulsions are adjustable and multifunctional, which makes them broadly applicable, such as for use as vaccine adjuvants[172] and for the development of new drug delivery methods. The surface adjustability, high loading capacity, safety, and slow-release characteristics of nanoemulsions particles[173] can be utilized to encapsulate antiviral drugs such as COVID-19 vaccines[174] and antibacterial drugs, which have great application prospects. Emulsions have been used as safe delivery platforms for vaccines.[175] Targeting viruses through epitopes or targeted fragments displayed on the surface of nanoemulsions droplet particles or modifying phospholipids with polyethylene glycol can effectively prevent the phagocytosis of macrophages, allowing for drugs to achieve long-term circulation effects in the body,[176] resulting in improved therapeutic effects. In terms of structural modification, the preparation of multiphase emulsions can make them more complex and result in a potentially a wider range of applications. The multiple internalized phases of multiphase nanoemulsions can achieve various chemical zones to control the release of active ingredients and complex particle templates.[177] The chitosan-modified multiphase nanoemulsions prepared by Malik et al enhanced the permeability of the stratum corneum when applied to the skin, significantly improving the permeability and retention of drugs and enhancing the efficacy of skin infection treatment.[178] The complex structure of multiphase nanoemulsions also leads to harsh preparation conditions and limitations in large-scale production. In addition, the limitations of encapsulation efficiency and the preparation of multiple nanoemulsions inevitably lead to an increase in droplet size. Maintaining a small droplet size while maximizing the encapsulation efficiency of the contents is an area of great expectation and concern. As a drug delivery carrier, further characterization of the physicochemical properties of the prepared nanoemulsions are necessary, and many basic studies are needed to conduct pharmacological and toxicological evaluations as well as in vivo tests to minimize their toxic side effects.

Food Science

According to keyword list 6, the antibacterial and antioxidant capabilities of nanoemulsions are of greatest concern to food experts. There are five related words in the top 30 keywords, indicating their importance. As the demand for healthy, safe, green and natural products is increasing daily, consumers are increasingly inclined to choose foods that contain no or few synthetic additives.[179] In addition, there is also a growing demand for food products with better microbial safety and freshness. Therefore, developing new types of food preservatives to inhibit the growth of bacteria and microorganisms is an area of current research interest among researchers.[180] Nanoemulsions have shown great potential in preserving basic foods such as meat or vegetables. As natural antimicrobial and antioxidant agents, they can replace synthetic additives while ensuring the biological activity of ingredients and lengthening the shelf-life of food. Essential oil nanoemulsions and chitosan nanoemulsions[181] have shown great application prospects in food preservation, especially in extending the shelf-life of muscle foods and the storage period of grains. Nonetheless, there is still much room for improvement in properly addressing the impact of essential oil additives or essential oil coatings[182] on food flavor and sensory perception and exploring the mechanism of chitosan more clearly. There is also room for improvement in proposing valuable research results for the scientific community. Additional in vitro experiments and more powerful technical support are needed to develop nanoemulsions as food additives with daily maximum intake and recommended intake levels. More in vivo studies should be conducted to clarify their interactions with biological systems in the human body and their digestion and absorption mechanisms in the gastrointestinal tract.[183] Therefore, it is necessary to explore the bioaccumulation of compounds and the storage and excretion of metabolites and establish consumer confidence[184] to promote and expand the benefits and potential of nanoemulsions in food applications.

Essential oil nanoemulsions have great applications in the food industry, as essential oil nanoemulsions not only possess the powerful antibacterial,[185] antiviral and antifungal[186] properties of essential oils but also have better dispersibility,[187] stronger bioactivity and better sensory properties.[188] The wetting ability of surfactants and emulsifiers also helps enhance the antibacterial activity of essential oil nanoemulsions[189] and has the least impact on the sensory properties of the product, thus broadening their applications in many products. Furthermore, studies have reported that combining essential oil nanoliposomes with vacuum packaging can further increase their antibacterial activity, which has great potential.[190] Although the use of nanoemulsions as a delivery method to encapsulate hydrophobic drugs, essential oils, etc, has shown good advantages, as food additives, the safety and toxicological evaluation of nanoemulsions is indispensable. The use of essential oil nanoemulsions as alternatives to traditional chemical preservatives is still in the early stages of exploration and application, and relevant technologies, regulations and policy support are not yet fully established.[191] The use of commonly used emulsifiers such as ionic surfactants[192] and nonionic surfactants[193] poses a great threat to the safety of nanoemulsions. Therefore, while preparing nanoemulsions, it is necessary to improve relevant research ideas, change the current commonly used surfactants to develop new surfactants, further characterize their physicochemical properties, support research on the effects of surfactants on the particle size and stability of nanoemulsions with more numerical and model support, investigate new combinations and optimize new formulations,[194] reduce costs, and ensure safety to a greater extent. Better preservation and improvement of the characteristics and stability of nanoemulsions antibacterial agents requires more innovative methods and strategies.[195] In addition, there is an urgent need for safer, more widely applicable natural emulsifiers and more advanced preparation techniques, with a greater focus on their synergistic effects and mechanisms of action, to ensure the safety and effectiveness of nanoemulsions and meet the requirements in more scenarios. Furthermore, the content and purity of natural emulsifiers are difficult to standardize because of differences in their source plant growth areas, developmental stages, collection sites, and collection times. The standardization and industrialization of their development is also an urgent problem that needs to be addressed.

Agricultural Science

In the field of agriculture, in terms of research direction, the great application potential of nanoemulsions is reflected mainly in the direction of plant science and entomology, owing to their application in the transportation of nutrient fertilizers,[196] pesticides and insecticides during agricultural planting. A nanoemulsions is a surfactant-stabilized oil–water two-phase dispersion that can increase the solubility and bioavailability of fertilizers, and the droplet size is very small; thus, the use of a nanoemulsions in plant and pest treatment can more easily penetrate the plant tissues and the cuticles of pests.[197] Owing to their relatively high specific surface area, encapsulating pesticides in nanoemulsions can better utilize the active ingredients and directly deliver them to the site of action, reducing the amount of pesticide used and minimizing their impact on the environment.[198] In addition, encapsulating nutrients such as various fertilizers, nutrients, and minerals in droplets is also more conducive to plant absorption and utilization, improving the health status and productivity of the plant and preventing fertilizer loss due to runoff or leaching.[199] This approach can improve plant efficiency and play an important role in agricultural planting. The application prospects of nanoemulsions in agriculture are gradually expanding. The development of new advanced nanoemulsions carriers, such as plant growth regulators,[200] growth hormones,[201] antibacterial agents and biological pesticides,[202] will be beneficial for the efficient, innovative and sustainable development of entire agricultural field.

Energy Science

Owing to the depletion of fossil fuels and the reduction in harmful emissions from diesel engines, scientists have been searching for new fuels as replacements.[203–206] Biodiesel, such as pure lemongrass oil,[207] safflower seed oil,[208] and apricot seed oil,[209] has shown good potential for energy conservation and emission reduction. The application of nanoemulsions in the energy field has focused mainly on reducing the exhaust emissions of biodiesel and improving the oil and gas recovery efficiency.[210] Kumar et al studied the performance of diesel engines fueled by waste orange peel oil nanoemulsions. The results showed that at maximum power output, compared with those of pure orange oil biodiesel fuel, the peak cylinder pressure and heat release rate of orange oil biodiesel nanoemulsions fuel increased.[211] Research indicates that the aqueous phase in diesel emulsions can reduce combustion temperatures and lower harmful emissions from diesel engines.[212] Water increases the kinematic viscosity and calorific value of fuel.[213] Biodiesel nanoemulsions not only increase combustion efficiency but also significantly reduce emissions of nitrogen oxides such as CO and NOx, as well as sulfur oxides, minimizing environmental harm. In the future, optimizing the economic and formulation aspects of biodiesel nanoemulsions will be a key focus of research.[214] In terms of oil and gas recovery, the surfactant in the nanoemulsions accumulates more around the oil core, and the free surfactant molecules in the continuous phase decrease, thus reducing the loss caused by the adsorption of surfactant on the rock surface during oil and gas recovery.[215] Wei et al prepared a series of surfactant-stabilized oil-in-water nanoemulsions and conducted imbibition tests on tight cores compared with saline water. The results showed that nano-oil droplets can promote the ultimate recovery of crude oil.[216] The mechanism by which nanoemulsions enhance oil recovery is manifested mainly in the emulsification of crude oil, which reduces the interfacial tension between oil and water through surfactants, reverses wettability, and expands the swept area.[215] Nonetheless, there is still a lack of clarification of its adsorption characteristics and diffusion behavior, which requires further research. In addition, studies have shown that nanoemulsions can improve the energy conversion efficiency and durability in electrochemical applications.[217]

New Characterization Methods

It is also critical to innovate the characterization methods of nanoemulsions to better understand their properties. Currently, research on the characterization of nanoemulsions mainly focuses on the measurement of droplet size, size distribution, and zeta potential, which is very limited. Seeking new experimental techniques to evaluate all aspects of nanoemulsions can promote better understanding and broaden their applications and potential. Nanoparticle tracking analysis (NTA) uses a combination of laser scattering microscopy and CCD cameras to visualize and record the motion of nanoparticles in solution.[218] It can better identify and track individual particles undergoing Brownian motion to observe their movement state.[219] Small-angle X-ray scattering (SAXS) is an analytical technology that can detect relatively large, often nanoscale material structures through small-angle scattering signals. SAXS can be used to observe the size, shape, and morphology of nanoemulsions droplets and can dynamically follow their microscopic changes as they change with temperature. Compared with conventional transmission electron microscopy and scanning electron microscopy, SAXS requires less sample volume and is nondestructive.[220] Raman spectroscopy is used to analyze scattering spectra with different frequencies from incident light, which allows for a more detailed observation of vibrational and rotational information at the molecular level. Through the analysis of sample characteristic peaks, the stability of nanoemulsions-encapsulated substances can be studied. Uzun et al conducted Raman spectroscopy analysis on lutein nanoemulsions, confirming the stability of lutein after emulsification and stabilization.[221] Veloso et al used surface-enhanced Raman spectroscopy to evaluate the photodynamic therapy of breast cancer cells in mice via a nanoemulsions loaded with a chloroaluminum phthalocyanine photosensitizer. They selected the Raman modes of proteins at 608 cm(−1) and lipids at 1231 cm(−1) to follow up on the survival rate of tumor cells, envisioning the rapid development of quantitative infrared thermal imaging.[222] In addition to the above methods, nuclear magnetic resonance,[223] lipophilic fluorescent probes,[224] and imaging techniques[225] can be used as emerging characterization techniques to understand the stability, surface modification, release mechanism, and in vivo metabolism of nanoemulsions droplets. Introduction of more innovative nanoemulsions characterization experimental methods, examination of the characteristics behind nanoemulsions and optimization of formulations have great potential.

New Preparation Methods

At present, most methods for preparing nanoemulsions are high-energy emulsification methods, which require high energy consumption and high production equipment costs. In addition, low-energy emulsification methods require much energy during emulsification and a large amount of emulsifier, which poses certain challenges to the safety of nanoemulsions. Thus, it is necessary to find new preparation techniques. Recently, the process of emulsifying droplets via a metal organic framework (Mof) has gradually attracted the attention of researchers. Mofs are a new type of crystalline nanocomposite with a large surface area, surface adjustability, and high porosity.[226] They also have a topological structure and can be used as an amphiphilic and surface-active material to emulsify droplets into emulsions.

Studies have reported that Mof materials can better stabilize nanoemulsions, but the safety level requirements for nanoemulsions applied in the pharmaceutical or food industries are high, and some Mof materials prepared from metal or nonfood-grade organic linkers cannot meet safety requirements. To overcome this limitation, Chao et al used less toxic alkaline earth metals and an edible cyclodextrin-based Mof, which were stabilized by glycyrrhizic acid, and achieved good results,[227] verifying the possibility of guiding the stability of edible-grade nanoemulsions. However, the preparation of nanocarriers based on Mof materials still requires long-term toxicity verification and the exploration of safer and more effective stabilizers. The preparation of safer and long-term stable nanoemulsions will broaden their potential applications as delivery systems in the fields of medicine and food.

Limitations

This study has certain limitations. First, some studies that do not use the same search strategy may be excluded from this study. Second, studies without author keywords were not included. Third, compared with newly published articles, older articles tend to receive more citations over time; therefore, the advantages of recent publications may not be apparent in this study.

Conclusions and Outlook

The present study used the bibliometric method and DDA software to study the literature published in SCIE and SSCI journals in the field of nanoemulsions research from 2013–2023. Both developed countries, represented by the USA, and developing countries, represented by China and India, have made important contributions to the field. With the pursuit of safer, more effective, environmentally friendly[228] and more compliant nanoemulsions materials, the raw materials that meet different uses can be made into nanoemulsions forms to better meet researchers' needs. In the fields of medicine, food, cosmetics and pesticide products, the superior antioxidant, slow-release and antibacterial properties of nanoemulsions can be better utilized to a greater extent. In the field of energy, nanoemulsions have the potential for energy savings and emissions reduction. However, to meet more application requirements and higher safety requirements, improvements and updates in nanoemulsions preparation technology and the treatment of waste nanoemulsions,[229] as well as the possibility of new natural surfactants and droplet surface modifications, will increase the potential for the application of nanoemulsions and the development of green, natural, safe and high-performance multifunctional structural nanoemulsions. Further research is necessary in terms of reducing the preparation costs, improving preparation technology, conducting stability studies, and seeking better and safer surfactants. New characterization techniques for determining the characteristics of nanoemulsions, new preparation techniques mediated by Mof materials,[230–232] nanoemulsions carriers for delivering RNA,[233] and artificial intelligence in the development and optimization of nanoemulsions technology[234–236] will become research hotspots in the future, further promoting the large-scale production and application of nanoemulsions. This study provides a novel perspective on the current research status of nanoemulsions and analyzes and summarizes current research hotspots. Hence, it can provide inspiration and useful information for researchers to expand their ideas and find more potential development directions.

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References

1. Singh Y, Meher JG, Raval K, et al. Nanoemulsion: concepts, development and applications in drug delivery. *J Control Release*. 2017;252:28–49. doi:10.1016/j.jconrel.2017.03.008
2. Tadros T, Izquierdo R, Esquena J, Solans C. Formation and stability of nano-emulsions. *Adv Colloid Interface Sci*. 2004;108:303–318. doi:10.1016/j.cis.2003.10.023
3. Solans C, Izquierdo P, Nolla J, Azemar N, Garcia-Celma MJ. Nano-emulsions. *Curr Opin Colloid Interface Sci*. 2005;10(3–4):102–110. doi:10.1016/j.cocis.2005.06.004

4. Ozogul Y, Karsli GT, Durmus M, et al. Recent developments in industrial applications of nanoemulsions. *Adv Colloid Interface Sci*. 2022;304: 102685.
5. Kaur M, Garg T, Rath G, Goyal AK. Current nanotechnological strategies for effective delivery of bioactive drug molecules in the treatment of tuberculosis. *Crit Rev Ther Drug Carrier Syst*. 2014;31(1):49–88. doi:10.1615/CritRevTherDrugCarrierSyst.2014008285
6. Hu C, Zhang WN. Micro/nano emulsion delivery systems: effects of potato protein/chitosan complex on the stability, oxidizability, digestibility and β-carotene release characteristics of the emulsion. *Innovative Food Sci Emerg Technol*. 2022;77: 102980.
7. Souto EB, Cano A, Martins-Gomes C, Coutinho TE, Zielinska A, Silva AM. Microemulsions and nanoemulsions in skin drug delivery. *Bioengineering-Basel*. 2022;9(4):158.
8. Wang LJ, Li XF, Zhang GY, Dong JF, Eastoe J. Oil-in-water nanoemulsions for pesticide formulations. *J Colloid Interface Sci*. 2007;314 (1):230–235. doi:10.1016/j.jcis.2007.04.079
9. Anuar N, Sabri AH, Effendi TJB, Hamid KA. Development and characterisation of ibuprofen-loaded nanoemulsion with enhanced oral bioavailability. *Heliyon*. 2020;6(7):e04570. doi:10.1016/j.heliyon.2020.e04570
10. De Rubis G, Paudel KR, Manandhar B, et al. Agarwood oil nanoemulsion attenuates cigarette smoke-induced inflammation and oxidative stress markers in BCi-NS1.1 airway epithelial cells. *Nutrients*. 2023;15(4):1019. doi:10.3390/nu15041019
11. Zhang L, Wang SL, Zhang MH, Sun J. Nanocarriers for oral drug delivery. *J Drug Targeting*. 2013;21(6):515–527. doi:10.3109/1061186X.2013.789033
12. Gul U, Khan MI, Madni A, et al. Olive oil and clove oil-based nanoemulsion for topical delivery of terbinafine hydrochloride: in vitro and ex vivo evaluation. *Drug Delivery*. 2022;29(1):600–612. doi:10.1080/10717544.2022.2039805
13. Tavakoli M, Mahboobian MM, Nouri F, Mohammadi M. Studying the ophthalmic toxicity potential of developed ketoconazole loaded nanoemulsion in situ gel formulation for ophthalmic administration. *Toxicol Mech Methods*. 2021;31(8):572–580. doi:10.1080/15376516.2021.1941461
14. Elbardisy B, Boraie N, Galal S. Tadalafil nanoemulsion mists for treatment of pediatric pulmonary hypertension via nebulization. *Pharmaceutics*. 2022;14(12):2717. doi:10.3390/pharmaceutics14122717
15. Pidaparthi K, Suares D. Comparison of nanoemulsion and aqueous micelle systems of paliperidone for intranasal delivery. *AAPS Pharm Sci Tech*. 2017;18(5):1710–1719. doi:10.1208/s12249-016-0640-x
16. Rhim JW, Eom Y, Yoon EG, et al. Efficacy of a 0.05% cyclosporine a topical nanoemulsion in dry eyes with obstructive meibomian gland dysfunction. *Jpn J Ophthalmol*. 2022;66(3):254–263. doi:10.1007/s10384-022-00906-3
17. Hosny KM. Development of saquinavir mesylate nanoemulsion-loaded transdermal films: two-step optimization of permeation parameters, characterization, and ex vivo and in vivo evaluation. *Int J Nanomed*. 2019;14:8589–8601. doi:10.2147/IJN.S230747
18. Fernandes DA. Review on the applications of nanoemulsions in cancer theranostics. *J Mater Res*. 2022;37(12):1953–1977. doi:10.1557/s43578-022-00583-5
19. Wong PT, Goff PH, Sun RJ, et al. Combined intranasal nanoemulsion and RIG-I activating RNA adjuvants enhance mucosal, humoral, and cellular immunity to influenza virus. *Mol Pharmaceut*. 2021;18(2):679–698. doi:10.1021/acs.molpharmaceut.0c00315
20. Moghassemi S, Dadashzadeh A, Azevedo RB, Amorim CA. Nanoemulsion applications in photodynamic therapy. *J Control Release*. 2022;351:164–173. doi:10.1016/j.jconrel.2022.09.035
21. Zapolnik P, Pyrkosz A. Nanoemulsions as gene delivery in mucopolysaccharidosis type I-A mini-review. *Int J Mol Sci*. 2022;23(9):4785. doi:10.3390/ijms23094785
22. Kuai XP, Zhu YF, Yuan Z, et al. Perfluorooctyl bromide nanoemulsions holding MnO_2 nanoparticles with dual-modality imaging and glutathione depletion enhanced HIFU-eliciting tumor immunogenic cell death. *Acta Pharmaceutica Sinica B*. 2022;12(2):967–981. doi:10.1016/j.apsb.2021.07.025
23. Bogers WM, Oostermeijer H, Mooij P, et al. Potent immune responses in rhesus macaques induced by nonviral delivery of a self-amplifying RNA vaccine expressing HIV type 1 envelope with a cationic nanoemulsion. *J Infect Dis*. 2015;211(6):947–955. doi:10.1093/infdis/jiu522
24. Shukla RP, Tiwari P, Sardar A, et al. Alendronate-functionalized porous nano-crystalsomes mitigate osteolysis and consequent inhibition of tumor growth in a tibia-induced metastasis model. *J Control Release*. 2024;372:331–346. doi:10.1016/j.jconrel.2024.06.009
25. Borrajo ML, Quijano A, Lapuhs P, et al. Ionizable nanoemulsions for RNA delivery into the central nervous system - importance of diffusivity. *J Control Release*. 2024;372:295–303. doi:10.1016/j.jconrel.2024.06.051
26. Rodrigues MC, Junior WTD, Mundim T, et al. Induction of immunogenic cell death by photodynamic therapy mediated by aluminum-phthalocyanine in nanoemulsion. *Pharmaceutics*. 2022;14(1):196. doi:10.3390/pharmaceutics14010196
27. Torchilin VP. Multifunctional nanocarriers. *Adv Drug Delivery Rev*. 2006;58(14):1532–1555. doi:10.1016/j.addr.2006.09.009
28. Li B, Tan TF, Chu WW, et al. Co-delivery of paclitaxel (PTX) and docosahexaenoic acid (DHA) by targeting lipid nanoemulsions for cancer therapy. *Drug Delivery*. 2022;29(1):75–88. doi:10.1080/10717544.2021.2018523
29. Makidon PE, Nigavekar SS, Bielinska AU, et al. Characterization of stability and nasal delivery systems for immunization with nanoemulsion-based vaccines. *J Aerosol Med Pulmonary Drug Delivery*. 2010;23(2):77–89. doi:10.1089/jamp.2009.0766
30. Rai M, Lakra P, Yadav H, Maiti S. Nanoemulsion-laden poly(vinyl) alcohol hydrogel films for transdermal delivery of carbamazepine. *J Vinyl Addit Technol*. 2024;30:1254–1269. doi:10.1002/vnl.22116
31. Silva CAL, Azevedo CA, Pereira G, et al. Vitamin E nanoemulsion activity on stored red blood cells. *Transfus Med*. 2017;27(3):213–217. doi:10.1111/tme.12394
32. Poulose N, Sajayan A, Ravindran A, et al. Anti-diabetic potential of a stigmasterol from the seaweed gelidium spinosum and its application in the formulation of nanoemulsion conjugate for the development of functional biscuits. *Front Nutr*. 2021;8: 694362.
33. Mehmood T, Ahmed A, Ahmed Z. Food-grade nanoemulsions for the effective delivery of β-carotene. *Langmuir*. 2021;37(10):3086–3092. doi:10.1021/acs.langmuir.0c03399
34. Ting P, Srinuanchai W, Suttisansanee U, et al. Development of chrysin loaded oil-in-water nanoemulsion for improving bioaccessibility. *Foods*. 2021;10(8):1912. doi:10.3390/foods10081912
35. Otoni CG, de Moura MR, Aouada FA, et al. Antimicrobial and physical-mechanical properties of pectin/papaya puree/cinnamaldehyde nanoemulsion edible composite films. *Food Hydrocoll*. 2014;41:188–194. doi:10.1016/j.foodhyd.2014.04.013

36. McClements DJ. Edible nanoemulsions: fabrication, properties, and functional performance. *Soft Matter*. 2011;7(6):2297–2316. doi:10.1039/C0SM00549E
37. Kong IN, Degraeve P, Pui LP. Polysaccharide-based edible films incorporated with essential oil nanoemulsions: physico-chemical, mechanical properties and its application in food preservation-a review. *Foods*. 2022;11(4):555. doi:10.3390/foods11040555
38. Islam F, Saeed F, Afzaal M, Hussain M, Ikram A, Khalid MA. Food grade nanoemulsions: promising delivery systems for functional ingredients. *J Food Sci Technol Mysore*. 2023;60(5):1461–1471. doi:10.1007/s13197-022-05387-3
39. Li Z, Jiang XX, Huang H, et al. Chitosan/zein films incorporated with essential oil nanoparticles and nanoemulsions: similarities and differences. *Int J Biol Macromol*. 2022;208:983–994. doi:10.1016/j.ijbiomac.2022.03.200
40. Yazdan-Bakhsh M, Nasr-Esfahani M, Esmaeilzadeh-Kenari R, Fazel-Najafabadi M. Evaluation of antioxidant properties of Heracleum Lasiopetalum extract in multilayer nanoemulsion with biopolymer coating to control oxidative stability of sunflower oil. *J Food Measure Character*. 2021;15(2):1014–1023. doi:10.1007/s11694-020-00691-y
41. Sindi AM, Hosny KM, Rizg WY, et al. Utilization of experimental design in the formulation and optimization of hyaluronic acid-based nanoemulgel loaded with a turmeric-curry leaf oil nanoemulsion for gingivitis. *Drug Delivery*. 2023;30(1). doi:10.1080/10717544.2023.2184311
42. Padrilah SN, Samsudin NIP, Shukor MYA, Masdor NA. Nanoemulsion strategies in controlling fungal contamination and toxin production on grain corn using essential oils. *Green Chem Lett Rev*. 2024;17(1). doi:10.1080/17518253.2024.2315138
43. Ryu V, McClements DJ, Corradini MG, Yang JSH, McLandsborough L. Natural antimicrobial delivery systems: formulation, antimicrobial activity, and mechanism of action of quillaja saponin-stabilized carvacrol nanoemulsions. *Food Hydrocoll*. 2018;82:442–450. doi:10.1016/j.foodhyd.2018.04.017
44. Ryu V, McClements DJ, Corradini MG, McLandsborough L. Effect of ripening inhibitor type on formation, stability, and antimicrobial activity of thyme oil nanoemulsion. *Food Chem*. 2018;245:104–111. doi:10.1016/j.foodchem.2017.10.084
45. Özakar E, Alparslan L, Adigüzel MC, et al. A comprehensive study on peppermint oil and cinnamon oil as nanoemulsion: preparation, stability, cytotoxicity, antimicrobial, antifungal, and antioxidant activity. *Current Drug Delivery*. 2024;21(4):603–622. doi:10.2174/1567201820666230612123011
46. Napiorkówska A, Khaneghah AM, Kurek MA. Essential oil nanoemulsions-a new strategy to extend the shelf life of smoothies. *Foods*. 2024;13(12):1854. doi:10.3390/foods13121854
47. Donsì F, Ferrari G. Essential oil nanoemulsions as antimicrobial agents in food. *J Biotechnol*. 2016;233:106–120. doi:10.1016/j.jbiotec.2016.07.005
48. Lavanya M, Namasivayam SKR, John A. Developmental formulation principles of food preservatives by nanoencapsulation-fundamentals, application, and challenges. *Appl Biochem Biotechnol*. 2024;7503–7533. doi:10.1007/s12010-024-04943-1
49. Yang ZK, Li MR, Zhai XD, et al. Development and characterization of sodium alginate/tea tree essential oil nanoemulsion active film containing TiO_2 nanoparticles for banana packaging. *Int J Biol Macromol*. 2022;213:145–154. doi:10.1016/j.ijbiomac.2022.05.164
50. Li ZN, Zhang YX, Zhang ZA, et al. Microfluidic preparation of a novel phoxim nanoemulsion pesticide against Spodoptera litura. *Environ Sci Pollut Res*. 2022;29(39):59653–59665. doi:10.1007/s11356-022-20001-x
51. Zhang HH, Zhang YX, Cao C, Zhao PY, Huang QL, Cao LD. Optimization and characterization of pyraclostrobin nanoemulsion for pesticide delivery: improving activity, reducing toxicity, and protecting ecological environment. *Colloids Surfaces A*. 2024;692: 134051.
52. Feng JG, Chen QC, Wu XM, Jafari SM, McClements DJ. Formulation of oil-in-water emulsions for pesticide applications: impact of surfactant type and concentration on physical stability. *Environ Sci Pollut Res*. 2018;25(22):21742–21751. doi:10.1007/s11356-018-2183-z
53. Nie HY, Liao HX, Wen JR, et al. Foeniculum vulgare essential oil nanoemulsion inhibits Fusarium oxysporum causing Panax notoginseng root-rot disease. *J Ginseng Res*. 2024;48(2):236–244. doi:10.1016/j.jgr.2023.12.002
54. Nasser R, Ibrahim E, Fouad H, et al. Modulation of metagenomic, biochemical, and histo-morphological features in the termite Odontotermes formosanus through nanoemulsion treatment. *Ind Crops Prod*. 2024;217: 118866.
55. Gupta P, Preet S, Ananya, Singh N. Preparation of Thymus vulgaris (L.) essential oil nanoemulsion and its chitosan encapsulation for controlling mosquito vectors. *Sci Rep*. 2022;12(1):4335.
56. Maurya A, Singh VK, Das S, et al. Essential oil nanoemulsion as eco-friendly and safe preservative: bioefficacy against microbial food deterioration and toxin secretion, mode of action, and future opportunities. *Front Microbiol*. 2021;12: 751062.
57. Gawin-Mikolajewicz A, Nawrot U, Malec KH, Krajewska K, Nartowski KP, Karolewicz BL. The effect of high-pressure homogenization conditions on the physicochemical properties and stability of designed fluconazole-loaded ocular nanoemulsions. *Pharmaceutics*. 2024;16(1):11.
58. Kentish S, Wooster TJ, Ashokkumar A, Balachandran S, Mawson R, Simons L. The use of ultrasonics for nanoemulsion preparation. *Innovative Food Sci Emerg Technol*. 2008;9(2):170–175. doi:10.1016/j.ifset.2007.07.005
59. Hunter SJ, Elella MHA, Johnson EC, et al. Mucoadhesive pickering nanoemulsions via dynamic covalent chemistry. *J Colloid Interface Sci*. 2023;651:334–345. doi:10.1016/j.jcis.2023.07.162
60. Nakabayashi K, Yanagi H, Atobe M. Preparation of W/O nanoemulsion using tandem acoustic emulsification and its novel utilization as a medium for phase-transfer catalytic reaction. *RSC Adv*. 2014;4(101):57608–57610. doi:10.1039/C4RA09452B
61. Cholakova D, Vinarov Z, Tcholakova S, Denkov ND. Self-emulsification in chemical and pharmaceutical technologies. *Curr Opin Colloid Interface Sci*. 2022;59: 101576.
62. Koroleva MY, Yurtov EV. Nanoemulsions: the properties, methods of preparation and promising applications. *Russ Chem Rev*. 2012;81(1):21–43. doi:10.1070/RC2012v081n01ABEH004219
63. Palla CA, Aguilera-Garrido A, Carrín ME, Galisteo-González F, Gálvez-Ruiz MJ. Preparation of highly stable oleogel-based nanoemulsions for encapsulation and controlled release of curcumin. *Food Chem*. 2022;378: 132132.
64. Alam A, Alqarni MH, Foudah AI, Raish M, Salkini MA. Babchi oil-based nanoemulsion hydrogel for the management of psoriasis: a novel energy economic approach employing biosurfactants. *Gels*. 2022;8(12):761. doi:10.3390/gels8120761
65. McClements DJ. Nanoemulsions versus microemulsions: terminology, differences, and similarities. *Soft Matter*. 2012;8(6):1719–1729. doi:10.1039/C2SM06903B

66. Gupta A, Eral HB, Hatton TA, Doyle PS. Nanoemulsions: formation, properties and applications. *Soft Matter*. 2016;12(11):2826–2841. doi:10.1039/C5SM02958A
67. Guo YL, Zhang XP, Wang XH, Zhang L, Xu ZH, Sun DJ. Nanoemulsions stable against ostwald ripening. *Langmuir*. 2024;40(2):1364–1372. doi:10.1021/acs.langmuir.3c03019
68. Liu L, Niu JL, Wu JY. Development of highly stable paraffin wax/water phase change material nano-emulsions as potential coolants for thermal management. *Solar Energy Mater Solar Cells*. 2023;252: 112184.
69. Weerapol Y, Manmuan S, Chaothanaphat N, et al. Impact of fixed oil on ostwald ripening of anti-oral cancer nanoemulsions loaded with amomum kravanh essential oil. *Pharmaceutics*. 2022;14(5):938. doi:10.3390/pharmaceutics14050938
70. Teo A, Goh KKT, Wen JY, et al. Physicochemical properties of whey protein, lactoferrin and Tween 20 stabilised nanoemulsions: effect of temperature, pH and salt. *Food Chem*. 2016;197:297–306. doi:10.1016/j.foodchem.2015.10.086
71. Chong WT, Tang CP, Cheah YK, et al. Optimization of process parameters in preparation of tocotrienol-rich red palm oil-based nanoemulsion stabilized by Tween 80-Span 80 using response surface methodology. *PLoS One*. 2018;13(8):e0202771. doi:10.1371/journal.pone.0202771
72. Yi J, Fan YT, Zhang YZ, Zhao LQ. Characterization of catechin-α-lactalbumin conjugates and the improvement in β-carotene retention in an oil-in-water nanoemulsion. *Food Chem*. 2016;205:73–80. doi:10.1016/j.foodchem.2016.03.005
73. Zhu Y, Chen T, Feng TT, et al. Fabrication and biological activities of all-in-one composite nanoemulsion based on blumea balsamifera oil-tea tree oil. *Molecules*. 2023;28(15):5889.
74. Deng M, Chen HJ, Xie L, Liu K, Zhang XM, Li XF. Tea saponins as natural emulsifiers and cryoprotectants to prepare silymarin nanoemulsion. *LWT Food Sci Technol*. 2022;156: 113042.
75. Yang Y, Leser ME, Sher AA, McClements DJ. Formation and stability of emulsions using a natural small molecule surfactant: quillaja saponin (Q-Naturale®). *Food Hydrocoll*. 2013;30(2):589–596. doi:10.1016/j.foodhyd.2012.08.008
76. Schreiner TB, Dias MM, Barreiro MF, Pinho SP. Saponins as natural emulsifiers for nanoemulsions. *J Agri Food Chem*. 2022;70 (22):6573–6590. doi:10.1021/acs.jafc.1c07893
77. Taheri A, Jafari SM. Gum-based nanocarriers for the protection and delivery of food bioactive compounds. *Adv Colloid Interface Sci*. 2019;269:277–295. doi:10.1016/j.cis.2019.04.009
78. Assadpour E, Maghsoudlou Y, Jafari SM, Ghorbani M, Aalami M. Optimization of folic acid nano-emulsification and encapsulation by maltodextrin-whey protein double emulsions. *Int J Biol Macromol*. 2016;86:197–207. doi:10.1016/j.ijbiomac.2016.01.064
79. Donsì F, Annunziata M, Vincensi M, Ferrari G. Design of nanoemulsion-based delivery systems of natural antimicrobials: effect of the emulsifier. *J Biotechnol*. 2012;159(4):342–350. doi:10.1016/j.jbiotec.2011.07.001
80. Singh IR, Pulikkal AK. Nano emulsions stabilized by natural emulsifiers: a comprehensive review on feasibility, stability and bio-applicability. *J Drug Delivery Sci Technol*. 2024;92: 105303.
81. Donthu N, Kumar S, Mukherjee D, Pandey N, Lim WM. How to conduct a bibliometric analysis: an overview and guidelines. *J Bus Res*. 2021;133:285–296. doi:10.1016/j.jbusres.2021.04.070
82. Fang H, He LG, He HD, et al. The 100 most-cited articles in castration-resistant prostate cancer: a bibliometric analysis. *J Mens Health*. 2022;18(1):1.
83. Huang Y, Chen ZJ, Shen G, et al. Immune regulation and the tumor microenvironment in anti-PD-1/PDL-1 and anti-CTLA-4 therapies for cancer immune evasion: a bibliometric analysis. *Hum Vaccines Immunother*. 2024;20(1). doi:10.1080/21645515.2024.2318815
84. Sun GJ, Dong DS, Dong ZJ, et al. Drug repositioning: a bibliometric analysis. *Front Pharmacol*. 2022;13: 974849.
85. Sun GJ, Zhang Q, Dong ZJ, et al. Antibiotic resistant bacteria: a bibliometric review of literature. *Front Public Health*. 2022;10: 1002015.
86. He LG, Fang H, Wang XL, et al. The 100 most-cited articles in urological surgery: a bibliometric analysis. *Int J Surg*. 2020;75:74–79. doi:10.1016/j.ijsu.2019.12.030
87. Zhang DY, Zhang ZW, Managi S. A bibliometric analysis on green finance: current status, development, and future directions. *Finance Res Lett*. 2019;29:425–430. doi:10.1016/j.frl.2019.02.003
88. Vogel R, Güttel WH. The dynamic capability view in strategic management: a bibliometric review. *Int J Manage Rev*. 2013;15(4):426–446. doi:10.1111/ijmr.12000
89. Sharifi A. Urban sustainability assessment: an overview and bibliometric analysis. *Ecol Indic*. 2021;121: 107102.
90. Wu YQ, Cheng YX, Yang XL, Yu WY, Wan YH. Dyslexia: a bibliometric and visualization analysis. *Front Public Health*. 2022;10: :915053.
91. Ding Y, Chen DW, Ding XF, Wang G, Wan YH, Shen Q. A bibliometric analysis of income and cardiovascular disease status, hotspots, trends and outlook. *Medicine*. 2020;99(34):e21828. doi:10.1097/MD.0000000000021828
92. Wang C, Wu RH, Deng LL, Chen Y, Li YD, Wan YH. A bibliometric analysis on no-show research: status, hotspots, trends and outlook. *Sustainability*. 2020;12(10):3997.
93. Chen Y, Jin QX, Fang H, et al. Analytic network process: academic insights and perspectives analysis. *J Cleaner Prod*. 2019;235:1276–1294. doi:10.1016/j.jclepro.2019.07.016
94. Liu TF, Hu HL, Ding XF, et al. 12 years roadmap of the sulfur cathode for lithium sulfur batteries (2009-2020). *Energy Storage Mater*. 2020;30:346–366. doi:10.1016/j.ensm.2020.05.023
95. Sheng OW, Jin CB, Ding XF, et al. A decade of progress on solid-state electrolytes for secondary batteries: advances and contributions. *Adv Funct Mater*. 2021;31(27). doi:10.1002/adfm.202100891
96. Bai WY, Fang H, Wang YW, et al. Academic insights and perspectives in 3D printing: a bibliometric review. *Appl Sci-Basel*. 2021;11(18):8298.
97. Hirsch JE. An index to quantify an individual's scientific research output. *Proc Natl Acad Sci USA*. 2005;102(46):16569–16572. doi:10.1073/pnas.0507655102
98. Van Raan AFJ. Comparison of the Hirsch-index with standard bibliometric indicators and with peer judgment for 147 chemistry research groups. *Scientometrics*. 2006;67(3):491–502. doi:10.1556/Scient.67.2006.3.10
99. Braun T, Glänzel W, Schubert A. A Hirsch-type index for journals. *Scientist*. 2005;19(22):8.
100. Csajbók E, Berhidi A, Vasas L, Schubert A. Hirsch-index for countries based on essential science indicators data. *Scientometrics*. 2007;73 (1):91–117. doi:10.1007/s11192-007-1859-9
101. Alonso S, Cabrerizo FJ, Herrera-Viedma E, Herrera F. h-Index: a review focused in its variants, computation and standardization for different scientific fields. *J Informetrics*. 2009;3(4):273–289. doi:10.1016/j.joi.2009.04.001

102. Ma XY, Lu CX, Gao JW, Cao J, Wan YH, Fang H. Sustainability of new energy vehicles from a battery recycling perspective: a bibliometric analysis. *Heliyon*. 2024;10(13). doi:10.1016/j.heliyon.2024.e30169
103. Ghosh V, Mukherjee A, Chandrasekaran N. Ultrasonic emulsification of food-grade nanoemulsion formulation and evaluation of its bactericidal activity. *Ultrason Sonochem*. 2013;20(1):338–344. doi:10.1016/j.ultsonch.2012.08.010
104. Feng JG, Shi YL, Yu QY, Sun CC, Yang GT. Effect of emulsifying process on stability of pesticide nanoemulsions. *Colloids Surfaces A*. 2016;497:286–292.
105. Garfield E. The history and meaning of the journal impact factor. *JAMA J Am Med Assoc*. 2006;295(1):90–93. doi:10.1001/jama.295.1.90
106. Bornmann L, Daniel HD. What do we know about the h index? *J Am Soc Inf Sci Technol*. 2007;58(9):1381–1385. doi:10.1002/asi.20609
107. Liao HC, Tang M, Li ZM, Lev B. Bibliometric analysis for highly cited papers in operations research and management science from 2008 to 2017 based on Essential Science Indicators. *Omega-Int J Manage Sci*. 2019;88:223–236. doi:10.1016/j.omega.2018.11.005
108. Chen HQ, Wan YH, Jiang SA, Cheng YX. Alzheimer's disease research in the future: bibliometric analysis of cholinesterase inhibitors from 1993 to 2012. *Scientometrics*. 2014;98(3):1865–1877. doi:10.1007/s11192-013-1132-3
109. Erfani A, Pirouzifard MK, Almasi H, Gheybi N, Pirsa S. Application of cellulose plate modified with encapsulated Cinnamomum zeylanicum essential oil in active packaging of walnut kernel. *Food Chem*. 2022;381:132246.
110. Restrepo AE, Rojas JD, García OR, Sánchez LT, Pinzón MI, Villa CC. Mechanical, barrier, and color properties of banana starch edible films incorporated with nanoemulsions of lemongrass (Cymbopogon citratus) and rosemary (Rosmarinus officinalis) essential oils. *Food Sci Technol Int*. 2018;24(8):705–712. doi:10.1177/1082013218792133
111. Liu T, Gao ZP, Zhong WM, et al. Preparation, characterization, and antioxidant activity of nanoemulsions incorporating lemon essential oil. *Antioxidants*. 2022;11(4):650.
112. Nogueira JAP, Figueiredo A, Duarte JL, et al. Repellency effect of Pilocarpus spicatus A. St.-Hil essential oil and nanoemulsion against Rhipicephalus microplus larvae. *Exp Parasitol*. 2020;215: 107919.
113. Firooziyan S, Osanloo M, Basseri HR, et al. Nanoemulsion of Myrtus communis essential oil and evaluation of its larvicidal activity against Anopheles stephensi. *Arabian J Chem*. 2022;15(9):104064. doi:10.1016/j.arabjc.2022.104064
114. Seibert JB, Rodrigues IV, Carneiro SP, et al. Seasonality study of essential oil from leaves of Cymbopogon densiflorus and nanoemulsion development with antioxidant activity. *Flavour Fragrance J*. 2019;34(1):5–14. doi:10.1002/ffj.3472
115. Abdulaal WH, Hosny KM, Alhakamy NA, et al. Fabrication, assessment, and optimization of alendronate sodium nanoemulsion-based injectable in-situ gel formulation for management of osteoporosis. *Drug Delivery*. 2023;30(1). doi:10.1080/10717544.2022.2164094
116. El Makawy AI, Mabrouk DM, Ibrahim FM, et al. Formulation of quinoa oil-alginate loaded nanoemulsion and its anticancer efficacy as a therapy for chemically induced breast cancer. *Molecular Biology Reports*. 2024;51(1). doi:10.1007/s11033-024-09619-x
117. Anand P, Kunnumakkara AB, Newman RA, Aggarwal BB. Bioavailability of curcumin: problems and promises. *Mol Pharmaceut*. 2007;4 (6):807–818. doi:10.1021/mp700113r
118. Aggarwal BB, Kumar A, Bharti AC. Anticancer potential of curcumin: preclinical and clinical studies. *Anticancer Res*. 2003;23(1A):363–398.
119. Aggarwal BB, Sundaram C, Malani N, Ichikawa H. Curcumin: the Indian solid gold. *mol Targets Therap Uses Curcumin Health Dis*. 2007;595:1.
120. Galli GM, Gerbet RR, Griss LG, et al. Combination of herbal components (curcumin, carvacrol, thymol, cinnamaldehyde) in broiler chicken feed: impacts on response parameters, performance, fatty acid profiles, meat quality and control of coccidia and bacteria. *Microb Pathogenesis*. 2020;139: 103916.
121. Jiang T, Liao W, Charcosset C. Recent advances in encapsulation of curcumin in nanoemulsions: a review of encapsulation technologies, bioaccessibility and applications. *Food Res Int*. 2020;132: 109035.
122. Ciuca MD, Racovita RC. Curcumin: overview of extraction methods, health benefits, and encapsulation and delivery using microemulsions and nanoemulsions. *Int J mol Sci*. 2023;24(10):8874. doi:10.3390/ijms24108874
123. Ghanimatdan M, Sadjjadi SM, Mikaeili F, et al. Therapeutic effect of curcumin nanoemulsion on cystic echinococcosis in BALB/c mice: a computerized tomography (CT) scan and histopathologic study evaluation. *BMC Complement Med Therap*. 2024;24(1). doi:10.1186/s12906-024-04451-z
124. Ganta S, Amiji M. Coadministration of paclitaxel and curcumin in nanoemulsion formulations to overcome multidrug resistance in tumor cells. *Mol Pharmaceut*. 2009;6(3):928–939. doi:10.1021/mp800240j
125. Yu HL, Huang QR. Improving the oral bioavailability of curcumin using novel organogel-based nanoemulsions. *J Agri Food Chem*. 2012;60 (21):5373–5379. doi:10.1021/jf300609p
126. Tang SY, Manickam S, Wei TK, Nashiru B. Formulation development and optimization of a novel Cremophor EL-based nanoemulsion using ultrasound cavitation. *Ultrason Sonochem*. 2012;19(2):330–345. doi:10.1016/j.ultsonch.2011.07.001
127. Baspinar Y, Keck CM, Borchert HH. Development of a positively charged prednicarbate nanoemulsion. *Int J Pharm*. 2010;383(1–2):201–208. doi:10.1016/j.ijpharm.2009.09.002
128. Jores K, Mehnert W, Mäder K. Physicochemical investigations on solid lipid nanoparticles and on oil-loaded solid lipid nanoparticles:: a nuclear magnetic resonance and electron spin resonance study. *Pharm Res*. 2003;20(8):1274–1283. doi:10.1023/A:1025065418309
129. Flögel U, Ding Z, Hardung H, et al. In vivo monitoring of inflammation after cardiac and cerebral ischemia by fluorine magnetic resonance imaging. *Circulation*. 2008;118(2):140–148. doi:10.1161/CIRCULATIONAHA.107.737890
130. Sneha K, Kumar A. Nanoemulsions: techniques for the preparation and the recent advances in their food applications. *Innovative Food Sci Emerg Technol*. 2022;76: 102914.
131. Zhang WT, Jiang YX, He YL, et al. Lipid carriers for mRNA delivery. *Acta Pharmaceutica Sinica B*. 2023;13(10):4105–4126. doi:10.1016/j.apsb.2022.11.026
132. Karimi-Maleh H, Ghalkhani M, Dehkordi ZS, et al. Mof-enabled pesticides as developing approach for sustainable agriculture and reducing environmental hazards. *J Ind Eng Chem*. 2024;129:105–123. doi:10.1016/j.jiec.2023.08.044
133. Phatale V, Vaiphei KK, Jha S, Patil D, Agrawal M, Alexander A. Overcoming skin barriers through advanced transdermal drug delivery approaches. *J Control Release*. 2022;351:361–380. doi:10.1016/j.jconrel.2022.09.025
134. Haddadzadegan S, Dorkoosh F, Bernkop-Schnürch A. Oral delivery of therapeutic peptides and proteins: technology landscape of lipid-based nanocarriers. *Adv Drug Delivery Rev*. 2022;182: 114097.

135. Philip J. Magnetic nanofluids (Ferrofluids): recent advances, applications, challenges, and future directions. *Adv Colloid Interface Sci*. 2023;311 102810.
136. Wang ZY, Wang ZX, Lin SH, et al. Nanoparticle-templated nanofiltration membranes for ultrahigh performance desalination. *Nat Commun*. 2018;9. doi:10.1038/s41467-018-03463-x
137. van Straten D, Mashayekhi V, de Bruijn HS, Oliveira S, Robinson DJ. Oncologic photodynamic therapy: basic principles, current clinical status and future directions. *Cancers*. 2017;9(2). doi:10.3390/cancers9020019
138. McClements DJ, Jafari SM. Improving emulsion formation, stability and performance using mixed emulsifiers: a review. *Adv Colloid Interface Sci*. 2018;251:55–79. doi:10.1016/j.cis.2017.12.001
139. Jaiswal M, Dudhe R, Sharma PK. Nanoemulsion: an advanced mode of drug delivery system. *3 Biotech*. 2015;5(2):123–127. doi:10.1007/s13205-014-0214-0
140. Smith DM, Simon JK, Baker Jr JR. Applications of nanotechnology for immunology. *Nat Rev Immunol*. 2013;13(8):592–605. doi:10.1038/nri3488
141. Ezhilarasi PN, Karthik P, Chhanwal N, Anandharamakrishnan C. Nanoencapsulation techniques for food bioactive components: a review. *Food Bioprocess Technol*. 2013;6(3):628–647. doi:10.1007/s11947-012-0944-0
142. Peng L, Hung CT, Wang SW, et al. Versatile nanoemulsion assembly approach to synthesize functional mesoporous carbon nanospheres with tunable pore sizes and architectures. *J Am Chem Soc*. 2019;141(17):7073–7080. doi:10.1021/jacs.9b02091
143. Kharat M, Du ZY, Zhang GD, McClements DJ. Physical and chemical stability of curcumin in aqueous solutions and emulsions: impact of pH, temperature, and molecular environment. *J Agri Food Chem*. 2017;65(8):1525–1532. doi:10.1021/acs.jafc.6b04815
144. Sari TP, Mann B, Kumar R, et al. Preparation and characterization of nanoemulsion encapsulating curcumin. *Food Hydrocoll*. 2015;43:540–546. doi:10.1016/j.foodhyd.2014.07.011
145. Kah M, Hofmann T. Nanopesticide research: current trends and future priorities. *Environ Int*. 2014;63:224–235. doi:10.1016/j.envint.2013.11.015
146. Prasad R, Bhattacharyya A, Nguyen QD. Nanotechnology in sustainable agriculture: recent developments, challenges, and perspectives. *Front Microbiol*. 2017;8:8. doi:10.3389/fmicb.2017.00008
147. Kumar S, Nehra M, Dilbaghi N, Marrazza G, Hassan AA, Kim KH. Nano-based smart pesticide formulations: emerging opportunities for agriculture. *J Control Release*. 2019;294:131–153. doi:10.1016/j.jconrel.2018.12.012
148. Song XJ, Feng LZ, Liang C, Yang K, Liu Z. Ultrasound triggered tumor oxygenation with oxygen-shuttle nanoperfluorocarbon to overcome hypoxia-associated resistance in cancer therapies. *Nano Lett*. 2016;16(10):6145–6153. doi:10.1021/acs.nanolett.6b02365
149. Anselmo AC, Zhang MW, Kumar S, et al. Elasticity of nanoparticles influences their blood circulation, phagocytosis, endocytosis, and targeting. *Acs Nano*. 2015;9(3):3169–3177. doi:10.1021/acsnano.5b00147
150. Lu Y, Park K. Polymeric micelles and alternative nanonized delivery vehicles for poorly soluble drugs. *Int J Pharm*. 2013;453(1):198–214. doi:10.1016/j.ijpharm.2012.08.042
151. Salvia-Trujillo L, Qian C, Martín-Belloso O, McClements DJ. Influence of particle size on lipid digestion and β-carotene bioaccessibility in emulsions and nanoemulsions. *Food Chem*. 2013;141(2):1472–1480. doi:10.1016/j.foodchem.2013.03.050
152. Acevedo-Fani A, Salvia-Trujillo L, Rojas-Graü MA, Martín-Belloso O. Edible films from essential-oil-loaded nanoemulsions: physicochemical characterization and antimicrobial properties. *Food Hydrocoll*. 2015;47:168–177. doi:10.1016/j.foodhyd.2015.01.032
153. Roy A, Nishchaya K, Rai VK. Nanoemulsion-based dosage forms for the transdermal drug delivery applications: a review of recent advances. *Expert Opin Drug Delivery*. 2022;19(3):303–319. doi:10.1080/17425247.2022.2045944
154. Mahadev M, Nandini HS, Ramu R, et al. Fabrication and evaluation of quercetin nanoemulsion: a delivery system with improved bioavailability and therapeutic efficacy in diabetes mellitus. *Pharmaceuticals*. 2022;15(1):70. doi:10.3390/ph15010070
155. Ahmad N, Albassam AA, Khan MF, et al. A novel 5-Fluorouracil multiple-nanoemulsion used for the enhancement of oral bioavailability in the treatment of colorectal cancer. *Saudi J Biol Sci*. 2022;29(5):3704–3716. doi:10.1016/j.sjbs.2022.02.017
156. Basavaraju SM, Mudhol S, Peddha MS, et al. Nanoemulsion-based piperine to enhance bioavailability for the treatment of LPS-induced depression-like behaviour in mice. *Neurosci lett*. 2023;814: 137441.
157. Teixé-Roig J, Oms-Oliu G, Odriozola-Serrano I, Martín-Belloso O. Enhancing in vivo retinol bioavailability by incorporating ?-carotene from alga Dunaliella salina into nanoemulsions containing natural-based emulsifiers. *Food Res Int*. 2023;164: 112359.
158. Alshahrani SM. Development and optimization of oral nanoemulsion of rutin for enhancing its dissolution rate, permeability, and oral bioavailability. *Pharm Dev Technol*. 2022;27(5):588–597. doi:10.1080/10837450.2022.2090957
159. Diedrich C, Zittlau IC, Machado CS, et al. Mucoadhesive nanoemulsion enhances brain bioavailability of luteolin after intranasal administration and induces apoptosis to SH-SY5Y neuroblastoma cells. *Int J Pharm*. 2022;626: 122142.
160. Ali FR, Shoaib MH, Ali SA, et al. A nanoemulsion based transdermal delivery of insulin: formulation development, optimization, in-vitro permeation across Strat-M® membrane and its pharmacokinetic/pharmacodynamic evaluation. *J Drug Delivery Sci Technol*. 2022;71: 103338.
161. Pourmadadi M, Ahmadi M, Yazdian F. Synthesis of a novel pH-responsive Fe3O4/chitosan/agarose double nanoemulsion as a promising Nanocarrier with sustained release of curcumin to treat MCF-7 cell line. *Int J Biol Macromol*. 2023;235: 123786.
162. Tau J, Passerini MS, Del Papa M, Aguilar A, Berra A. A novel ophthalmic latanoprost 0.005% nanoemulsion: a cytotoxicity study. *Graefes Arch Clin Experiment Ophthalmol*. 2022;260(6):1941–1946. doi:10.1007/s00417-021-05536-y
163. Fukumori C, Branco PC, Barreto T, Ishida K, Lopes LB. Development and cytotoxicity evaluation of multiple nanoemulsions for oral co-delivery of 5-fluorouracil and short chain triglycerides for colorectal cancer. *Eur J Pharm Sci*. 2023;187: 123786.
164. Zhou F, Yu T, Du RH, et al. Clinical course and risk factors for mortality of adult inpatients with COVID-19 in Wuhan, China: a retrospective cohort study. *Lancet*. 2020;395(10229):1054–1062. doi:10.1016/S0140-6736(20)30566-3
165. Tayeb HH, Felimban R, Almaghrabi S, Hasaballah N. Nanoemulsions: formulation, characterization, biological fate, and potential role against COVID-19 and other viral outbreaks. *Colloid Interface Sci Commun*. 2021;45:100533.
166. Coates A, Hu YM, Bax R, Page C. The future challenges facing the development of new antimicrobial drugs. *Nat Rev Drug Discov*. 2002;1(11):895–910. doi:10.1038/nrd940
167. Jiang HY, Zhong SB, Schwarz P, Chen BC, Rao JJ. Antifungal activity, mycotoxin inhibitory efficacy, and mode of action of essential oil nanoemulsion Fusarium. *Food Chem*. 2023;400: 134016.

168. Nabawy A, Makabenta JM, Schmidt-Malan S, et al. Dual antimicrobial-loaded biodegradable nanoemulsions for synergistic treatment of wound biofilms. *J Control Release*. 2022;347:379–388. doi:10.1016/j.jconrel.2022.05.013
169. Juneja M, Suthar T, Pardhi VP, Ahmad J, Jain K. Emerging trends and promises of nanoemulsions in therapeutics of infectious diseases. *Nanomedicine*. 2022;17(11):793–812. doi:10.2217/nnm-2022-0006
170. Akkam Y, Rababah T, Costa R, et al. Pea protein nanoemulsion effectively stabilizes vitamin D in food products: a potential supplementation during the COVID-19 pandemic. *Nanomaterials*. 2021;11(4):887. doi:10.3390/nano11040887
171. Tulbah AS, Bader A, Ong HX, Traini D. In vitro evaluation of nebulized eucalyptol nano-emulsion formulation as a potential COVID-19 treatment. *Saudi Pharm J*. 2022;30(12):1691–1699. doi:10.1016/j.jsps.2022.09.014
172. Kocabiyik O, Amlashi P, Vo AL, et al. Vaccine targeting to mucosal lymphoid tissues promotes humoral immunity in the gastrointestinal tract. *Sci Adv*. 2024;10(22). doi:10.1126/sciadv.adn7786
173. Peng YR, Meng QL, Zhou J, et al. Nanoemulsion delivery system of tea polyphenols enhanced the bioavailability of catechins in rats. *Food Chem*. 2018;242:527–532. doi:10.1016/j.foodchem.2017.09.094
174. Assis BRD, Gomes IP, de Castro JT, et al. Quality attributes of CTVad1, a nanoemulsified adjuvant for Phase I clinical trial of SpiN COVID-19 vaccine. *Nanomedicine*. 2023;18(18):1175–1194. doi:10.2217/nnm-2023-0122
175. Mosca F, Tritto E, Muzzi A, et al. Molecular and cellular signatures of human vaccine adjuvants. *Proc Natl Acad Sci USA*. 2008;105 (30):10501–10506. doi:10.1073/pnas.0804699105
176. Dokovic JB, Savic SM, Mitrovic JR, et al. Curcumin loaded PEGylated nanoemulsions designed for maintained antioxidant effects and improved bioavailability: a pilot study on rats. *Int J mol Sci*. 2021;22(15):7991. doi:10.3390/ijms22157991
177. Sheth T, Seshadri S, Prileszky T, Helgeson ME. Multiple nanoemulsions. *Nature Rev Mater*. 2020;5(3):214–228. doi:10.1038/s41578-019-0161-9
178. Malik MR, Al-Harbi FF, Nawaz A, et al. Formulation and characterization of chitosan-decorated multiple nanoemulsion for topical delivery in vitro and ex vivo. *Molecules*. 2022;27(10):3183. doi:10.3390/molecules27103183
179. Prakash B, Kujur A, Yadav A, Kumar A, Singh PP, Dubey NK. Nanoencapsulation: an efficient technology to boost the antimicrobial potential of plant essential oils in food system. *Food Control*. 2018;89:1–11. doi:10.1016/j.foodcont.2018.01.018
180. El Asbahani A, Miladi K, Badri W, et al. Essential oils: from extraction to encapsulation. *Int J Pharm*. 2015;483(1–2):220–243. doi:10.1016/j.ijpharm.2014.12.069
181. Chaudhary S, Kumar V, Sharma V, Sharma R, Kumar S. Chitosan nanoemulsion: gleam into the futuristic approach for preserving the quality of muscle foods. *Int J Biol Macromol*. 2022;199:121–137. doi:10.1016/j.ijbiomac.2021.12.046
182. Travicic V, Cvanic T, Cetkovic G. Plant-based nano-emulsions as edible coatings in the extension of fruits and vegetables shelf life: a patent review. *Foods*. 2023;12(13):2535. doi:10.3390/foods12132535
183. Barzegar F, Nabizadeh S, Kamankesh M, Ghasemi JB, Mohammadi A. Recent advances in natural product-based nanoemulsions as promising substitutes for hazardous synthetic food additives: a new revolution in food processing. *Food Bioprocess Technol*. 2024;17(5):1087–1108. doi:10.1007/s11947-023-03162-6
184. Ujilestari T, Febrisiantosa A, Sholikin MM, Wahyuningsih R, Wahyono T. Nanoemulsion application in meat product and its functionality: review. *J Animal Sci Technol*. 2023;65(2):275–292. doi:10.5187/jast.2022.e120
185. Chu YF, Gao CC, Liu XY, et al. Improvement of storage quality of strawberries by pullulan coatings incorporated with cinnamon essential oil nanoemulsion. *LWT Food Sci Technol*. 2020;122: 109054.
186. Burt S. Essential oils: their antibacterial properties and potential applications in foods - a review. *Int J Food Microbiol*. 2004;94(3):223–253. doi:10.1016/j.ijfoodmicro.2004.03.022
187. Donsì F, Annunziata M, Sessa M, Ferrari G. Nanoencapsulation of essential oils to enhance their antimicrobial activity in foods. *LWT Food Sci Technol*. 2011;44(9):1908–1914. doi:10.1016/j.lwt.2011.03.003
188. Abdou ES, Galhoum GF, Mohamed EN. Curcumin loaded nanoemulsions/pectin coatings for refrigerated chicken fillets. *Food Hydrocoll*. 2018;83:445–453. doi:10.1016/j.foodhyd.2018.05.026
189. Ferreira JP, Alves D, Neves O, Silva J, Gibbs PA, Teixeira PC. Effects of the components of two antimicrobial emulsions on food-borne pathogens. *Food Control*. 2010;21(3):227–230. doi:10.1016/j.foodcont.2009.05.018
190. Zhao JX, Lan WQ, Xie J. Recent developments in nanoemulsions against spoilage in cold-stored fish: a review. *Food Chem*. 2023;429: 136876.
191. da Silva BD, Do Rosario DKA, Weitz DA, Conte-Junior CA. Essential oil nanoemulsions: properties, development, and application in meat and meat products. *Trends Food Sci Technol*. 2022;121:1–13. doi:10.1016/j.tifs.2022.01.026
192. Bazylinska U, Skrzela R, Piotrowski M, Szczepanowicz K, Warszynski P, Wilk KA. Influence of dicephalic ionic surfactant interactions with oppositely charged polyelectrolyte upon the in vitro dye release from oil core nanocapsules. *Bioelectrochemistry*. 2012;87:147–153. doi:10.1016/j.bioelechem.2011.10.006
193. Qian C, Decker EA, Xiao H, McClements DJ. Nanoemulsion delivery systems: influence of carrier oil on β-carotene bioaccessibility. *Food Chem*. 2012;135(3):1440–1447. doi:10.1016/j.foodchem.2012.06.047
194. Mariyate J, Bera A. A critical review on selection of microemulsions or nanoemulsions for enhanced oil recovery. *J Mol Liq*. 2022;353: 118791.
195. Sharma K, Babaei A, Oberoi K, Aayush K, Sharma R, Sharma S. Essential oil nanoemulsion edible coating in food industry: a review. *Food Bioprocess Technol*. 2022;15(11):2375–2395. doi:10.1007/s11947-022-02811-6
196. Giri VP, Shukla P, Tripathi A, et al. A review of sustainable use of biogenic nanoscale agro-materials to enhance stress tolerance and nutritional value of plants. *Plants-Basel*. 2023;12(4). doi:10.3390/plants12040815
197. Bamisaye A, Adegoke KA, Alli YA, Bamidele MO, Idowu MA, Ogunjinmi OE. Recent advances in nanoemulsion for sustainable development of farm-to-fork systems. *J Cleaner Prod*. 2023;429: 139226.
198. Khdair A, Abu-Rumman G. Sustainable environmental management and valorization options for olive mill byproducts in the Middle East and North Africa (MENA) region. *Processes*. 2020;8(6):671. doi:10.3390/pr8060671
199. Chhipa H. Nanofertilizers and nanopesticides for agriculture. *Environ Chem Lett*. 2017;15(1):15–22. doi:10.1007/s10311-016-0600-4
200. Acharya P, Jayaprakasha GK, Semper J, Patil BS. ^{1}H nuclear magnetic resonance and liquid chromatography coupled with mass spectrometry-based metabolomics reveal enhancement of growth-promoting metabolites in onion seedlings treated with green-synthesized nanomaterials. *J Agri Food Chem*. 2020;68(46):13206–13220. doi:10.1021/acs.jafc.0c00817

201. Alfaro-Almaguer JA, Mejía-Manzano LA, González-Valdez J. State-of-the-art and opportunities for bioactive pentacyclic triterpenes from Native Mexican plants. *Plants-Basel*. 2022;11(17). doi:10.3390/plants11172184
202. Zhang H, Qin H, Li LX, Zhou XT, Wang W, Kan CY. Preparation and characterization of controlled-release avermectin/castor oil-based polyurethane nanoemulsions. *J Agri Food Chem*. 2018;66(26):6552–6560. doi:10.1021/acs.jafc.7b01401
203. Alahmer A, Yamin J, Sakhrieh A, Hamdan MA. Engine performance using emulsified diesel fuel. *Energy Convers Manage*. 2010;51 (8):1708–1713. doi:10.1016/j.enconman.2009.11.044
204. Abdollahi M, Ghobadian B, Najafi G, Hoseini SS, Mofijur M, Mazlan M. Impact of water - biodiesel - diesel nano-emulsion fuel on performance parameters and diesel engine emission. *Fuel*. 2020;280: 118576.
205. Tong K, Zhao CH, Sun ZC, Sun DJ. Formation of concentrated nanoemulsion by W/O microemulsion dilution method: biodiesel, tween 80, and water system. *ACS Sustainable Chem Eng*. 2015;3(12):3299–3306. doi:10.1021/acssuschemeng.5b00903
206. Oo YM, Legwiriyakul A, Thawornprasert J, Somnuk K. Production of diesel-biodiesel-water fuel nanoemulsions using three-dimensional printed rotor-stator hydrodynamic cavitation. *Fuel*. 2022;317:123445.
207. Sathiyamoorthi R, Sankaranarayanan G, Pitchandi K. Combined effect of nanoemulsion and EGR on combustion and emission characteristics of neat lemongrass oil (LGO)-DEE-diesel blend fuelled diesel engine. *Appl Therm Eng*. 2017;112:1421–1432. doi:10.1016/j.applthermaleng.2016.10.179
208. Gongora B, de Souza SNM, Bassegio D, et al. Comparison of emissions and engine performance of safflower and commercial biodiesels. *Ind Crops Prod*. 2022;179: 114680.
209. Kim M, Choi D, Kim JY, et al. Direct conversion of apricot seeds into biodiesel. *Biores Technol*. 2024;395:130339. doi:10.1016/j.biortech.2024.130339
210. Xu H, Li Y, Zhou FJ, et al. Adsorption characteristics, isotherm, kinetics, and diffusion of nanoemulsion in tight sandstone reservoir. *Chem Eng J*. 2023;470: 144070.
211. Kumar ARM, Kannan M, Nataraj G. A study on performance, emission and combustion characteristics of diesel engine powered by nano-emulsion of waste orange peel oil biodiesel. *Renewable Energy*. 2020;146:1781–1795. doi:10.1016/j.renene.2019.06.168
212. Lif A, Holmberg K. Water-in-diesel emulsions and related systems. *Adv Colloid Interface Sci*. 2006;123:231–239. doi:10.1016/j.cis.2006.05.004
213. Lin CY, Lin HA. Effects of NO_x-inhibitor agent on fuel properties of three-phase biodiesel emulsions. *Fuel Process Technol*. 2008;89 (11):1237–1242. doi:10.1016/j.fuproc.2008.05.022
214. Koc AB, Abdullah M. Performance and NO_x emissions of a diesel engine fueled with biodiesel-diesel-water nanoemulsions. *Fuel Process Technol*. 2013;109:70–77. doi:10.1016/j.fuproc.2012.09.039
215. Kumar N, Mandal A. Surfactant stabilized oil-in-water nanoemulsion: stability, interfacial tension, and rheology study for enhanced oil recovery application. *Energy Fuels*. 2018;32(6):6452–6466. doi:10.1021/acs.energyfuels.8b00043
216. Wei B, Wang LL, Mao RX, et al. Understanding imbibition mechanisms of catanionic surfactant-stabilized nanoemulsion for enhanced oil recovery in tight sandstone reservoirs: experimental and numerical assessment. *Spe J*. 2023;28(3):1437–1452. doi:10.2118/204336-PA
217. Wan L, Xu Z, Cao QB, Liao YW, Wang BG, Liu K. Nanoemulsion-coated Ni-Fe hydroxide self-supported electrode as an air-breathing cathode for high-performance zinc-air batteries. *Nano Lett*. 2022;22(11):4535–4543. doi:10.1021/acs.nanolett.2c01388
218. Hansen H, Kijanka G, Ouyang LX, Nguyen NT, An HJ. Surfactant-free oil-in-water nanoemulsions with nanopore membrane and ultrasound. *J Mol Liq*. 2024;399: 124323.
219. Riachy P, Du N, Stébé MJ, Blin JL. Detailed investigation of nano-emulsions obtained from the Remcopal 4/decane/water system. *Colloids Surfaces A*. 2015;481:207–214.
220. Feng JH, Kriechbaum M, Liu L. In situ capabilities of small angle X-ray scattering. *Nanotechnol Rev*. 2019;8(1):352–369. doi:10.1515/ntrev-2019-0032
221. Uzun S, Kim H, Leal C, Padua GW. Ethanol-induced whey protein gels as carriers for lutein droplets. *Food Hydrocoll*. 2016;61:426–432. doi:10.1016/j.foodhyd.2016.05.013
222. Veloso AB, Longo JPF, Muehlmann LA, et al. SERS investigation of cancer cells treated with PDT: quantification of cell survival and follow-up. *Sci Rep*. 2017;7. doi:10.1038/s41598-017-07469-1
223. Janjic JM, Ahrens ET. Fluorine-containing nanoemulsions for MRI cell tracking. *Wiley Interdisciplin Rev Nanomed Nanobiotechnol*. 2009;1 (5):492–501. doi:10.1002/wnan.35
224. Gaoe H, Pang ZQ, Pan SQ, et al. Anti-glioma effect and safety of docetaxel-loaded nanoemulsion. *Arch Pharmacal Res*. 2012;35(2):333–341. doi:10.1007/s12272-012-0214-8
225. Vecchione R, Quagliariello V, Giustetto P, et al. Oil/water nano-emulsion loaded with cobalt ferrite oxide nanocubes for photo-acoustic and magnetic resonance dual imaging in cancer: in vitro and preclinical studies. *Nanomed Nanotechnol Biol Med*. 2017;13(1):275–286. doi:10.1016/j.nano.2016.08.022
226. Li HY, Lv NN, Li X, et al. Composite CD-MOF nanocrystals-containing microspheres for sustained drug delivery. *Nanoscale*. 2017;9 (22):7454–7463. doi:10.1039/C6NR07593B
227. Qiu C, Wang JP, Qin Y, Xu XM, Jin ZY. Characterization and mechanisms of novel emulsions and nanoemulsion gels stabilized by edible cyclodextrin-based metal-organic frameworks and glycyrrhizic acid. *J Agri Food Chem*. 2019;67(1):391–398. doi:10.1021/acs.jafc.8b03065
228. Barradas TN, Silva K. Nanoemulsions of essential oils to improve solubility, stability and permeability: a review. *Environ Chem Lett*. 2021;19 (2):1153–1171. doi:10.1007/s10311-020-01142-2
229. Xiong YJ, Peng KM, Zhao ZQ, Yang DL, Huang XF, Zeng HB. Sources, colloidal characteristics, and separation technologies for highly hazardous waste nanoemulsions. *Sci Total Environ*. 2024;930: 172347.
230. Hussain S, Wan XY, Fang Z, Peng XS. Superhydrophilic and photothermal Fe-TCPP nanofibrous membrane for efficient oil-in-water nanoemulsion separation. *Langmuir*. 2021;37(44):12981–12989. doi:10.1021/acs.langmuir.1c02046
231. Li XF, Wu XT, Xu Q, Zhu QL. Hierarchically ordered pore engineering of metal-organic framework-based materials for electrocatalysis. *Adv Mater*. 2024;36(27): 2401926.
232. Xu R, Ahn H, Kim S, Lee JW, Kang YT. CO2 capture enhancement by encapsulation of nanoparticles in metal-organic frameworks suspended in physical absorbents. *J CO2 Util*. 2023;69: 102397.

233. Chen G, Wang KK, Wu PK, et al. Development of fluorinated polyplex nanoemulsions for improved small interfering RNA delivery and cancer therapy. *Nano Res*. 2018;11(7):3746–3761. doi:10.1007/s12274-017-1946-z
234. Alshawwa SZ, Kassem AA, Farid RM, Mostafa SK, Labib GS. Nanocarrier drug delivery systems: characterization, limitations, future perspectives and implementation of artificial intelligence. *Pharmaceutics*. 2022;14(4):883. doi:10.3390/pharmaceutics14040883
235. Seela CR, Kalabarige LR, Kattela SP. Machine learning-based modeling of variable compression ratio engine performance and emissions with JME-ZnO nanoemulsion. *Energy Sourc Part Recovery Utili Environ Effec*. 2024;46(1):6038–6048. doi:10.1080/15567036.2024.2346159
236. Oye G, Simon S, Rustad T, Paso K. Trends in food emulsion technology: pickering, nano-, and double emulsions. *Curr Opin Food Sci*. 2023;50: 101003.

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