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Review

Environmentally Friendly Technologies for Wastewater Treatment in Food Processing Plants: A Bibliometric Analysis

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Abstract: Currently, the population is experiencing severe water stress mainly due to high water consumption by industries. Food and beverage processing consumes up to 90% of freshwater, resulting in large volumes of wastewater that is often treated with complex, costly and environmentally damaging processes. The purpose of this study is to perform the first bibliometric analysis to evaluate and discuss the evolution in the use of environmentally friendly technologies for wastewater treatment in food processing plants. A total of 606 documents published up to August 2022 were retrieved from Scopus. Data were manually standardized. VOSviewer version 1.5.18 and Bibliometrix version 4.0.0 were used to perform scientific mapping and evaluate bibliometric indicators of quantity, quality and structure. Scientific production is growing exponentially due to factors such as strict environmental policies and increased environmental awareness. The average number of authors per document is 4.056 and prolific authors in the field have not yet been defined. The contribution of the countries (led by the United States with 104 documents) was associated with their gross domestic product (GDP), level of trade and industrialization. Likewise, institutions from China (third place with 70 documents) have the highest contribution in the field. On the other hand, most of the journals where the documents were published are of high quality according to different metrics. According to the most influential articles, the frequency of keywords and their dynamics over time, the use of microalgae, microorganisms and plants for the treatment of effluents generated during food processing is the main trend. The processes also focus on the recovery or recycling of compounds of interest in wastewater such as phosphorus, nitrogen and carbon to contribute to the circular economy.

Keywords: wastewater; green technologies; food and beverage industry; microorganisms; microalgae; bibliometric study

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1. Introduction

Currently, 10% of the population does not have access to safe water, resulting in the death (directly and indirectly) of about 1 million people annually [1], approximately 300,000 children [2]. It was predicted that in a few decades 50% of the population will experience severe water stress [3]. According to Piesse [4], the reason is that water use has tripled since 1950; annual consumption increased from 1.22 billion cubic meters to 4 billion in 2014. This growth is double the population growth rate.

The increase in water demand is attributed to its massive use in industrial processes. Food and beverage processing ranks third in water consumption, accounting for up to 90% of the world's freshwater [5]. Figure 1 shows the water requirement to produce some foods. This industry generates vast quantities of wastewater (WW); a significant proportion is not treated and is discharged into lakes, rivers and open drains, damaging the environment and affecting the health of living beings [6,7]. The consequences depend on the characteristics (origin) of the effluent. Noukeu et al. [8] characterized effluents from 9 different food processing sectors and discussed the potential impact on the ecosystem. High concentrations of heavy metals such as cadmium and lead can inhibit plant growth and can also be toxic to humans and animals. Effluent discharge can increase the concentration of nitrogen compounds such as ammonium, nitrate and nitrite and cause eutrophication in water bodies. Low pH effluents can alter soil chemistry, affect nutrient bioavailability and increase the solubility of heavy metals. Oil and grease can reduce oxygenation in the water, affecting fish, algae and plant life. Excess solids can cause sedimentation and decrease water depth. The variation in the composition of water bodies causes changes in temperature and color, and can generate turbidity and unpleasant odors. For many other reasons, effluents generated in food processing must be treated before discharge. According to the United Nations report, the main reason for water scarcity is inadequate water management and non-reuse [9]. Water pinch analysis is a widely used strategy for water recycling. This approach is based on determining which waters generated in process A are of acceptable quality for reuse in process B. Therefore, it is essential to know the nature of each process, the minimum requirements of the water to be used and the characteristics of the effluent [10]. This also reduces the load of pollutants in the effluent [11]. Water pinch analysis has been successful in reducing freshwater consumption by 43% in sugar production [12], 63.5% in fruit juice production [13], 40% in soft drink production [14], 30% in beer production [15], 30% in citrus juice production [16] and 31.4–36% in corn production [17].

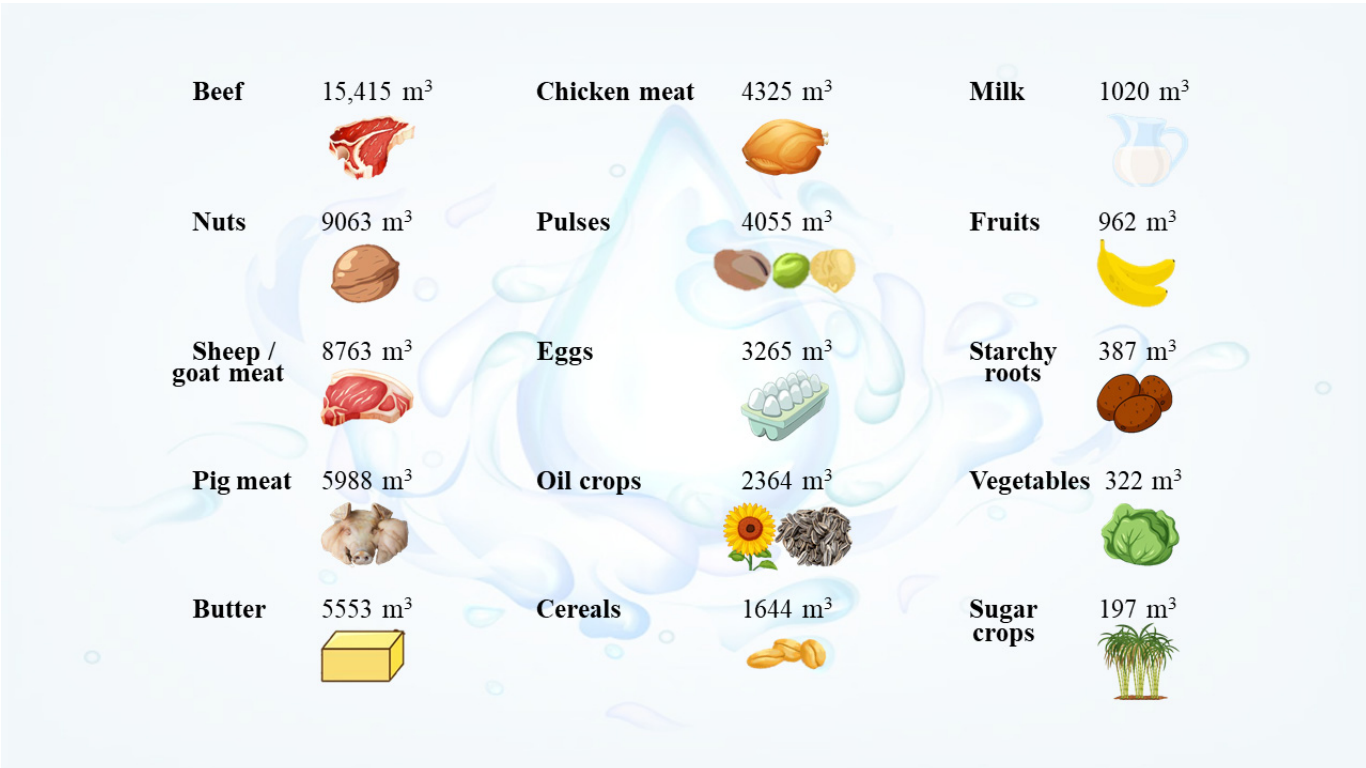

Figure 1. Water requirement to produce some foods (per ton). Based on information from Piesse [4].

Water consumption in the food industry depends on the number and type of raw materials and final products, the size of the processing plant, the processes and equipment used, automation and cleaning operations [5]. WW comes from operations/processes related to the handling and processing of raw materials. The composition of the effluent is subject to the quality of the water used, the type of processing and its treatment; it generally consists of organic matter, microorganisms, sanitation products, metals, fertilizers, pesticides, nutrients, organic and inorganic materials [5]. There are several alternatives for WW treatment; physicochemical systems such as gravity concentration, evaporation, centrifugation, sedimentation, coagulation, flocculation, adsorption, oxidation, filtration and flotation; biological systems such as bioremediation and/or aerobic and anaerobic biodegradation; and hybrid solutions [5,7,18].

Due to the complexity of the WW generated in food processing plants, it is difficult to select an efficient treatment. To know the state of research and important trends, bibliometrics is an effective tool for quantitative analysis using mathematical and statistical methods. The bibliometric method allows us to know the dynamics of the disciplines [19], the research interest in a field, the number of citations, which topics/keywords are booming, who the main authors are, which countries and institutions are involved, in which journals the results of studies are published, as well as their interrelations and information on the evolution over time [20,21]. This allows identification priorities to be identified, gaps in the literature to be filled and new lines of research to be developed.

Bibliometric studies have been conducted on WW treatment/management in general [20–27]. Some studies focused specifically on processes such as advanced oxidation [28–33], coagulation [34] and direct osmosis [35]. However, many of the treatments use chemicals that cause damage to the environment; they are expensive and ineffective [36]. Therefore, bibliometric studies were carried out on more efficient biological processes using microorganisms, algae and some plants [37–43]. In this sense, this study will perform the first bibliometric analysis to evaluate and discuss the evolution in the use of environmentally friendly technologies for WW treatment in food processing plants. The main purpose is to provide a broad overview of the dynamics and current state of research to professionals related to the field of study and to the general public interested in these topics. In addition, the information provided will make it possible to identify authors (for possible collaborations) and prolific countries (to define unexplored study areas, for example), select relevant articles (recent, high impact or on specific topics) to begin research, determine journals with the greatest potential for publishing research, etc.

2. Materials and Methods

The methodology used in a previous study was adapted [44]. The document search was performed in Scopus because it is the largest database of peer-reviewed literature, has high accessibility, and offers superior processing capabilities [45]. In order to carry out a more exhaustive and precise search, we chose to search for documents through the search terms [23]. After several tests, the search string was used: TITLE-ABS-KEY (“wastewater treatment” OR “sewage treatment”) AND technology AND (food OR beverage) AND (ecological OR environmental OR green OR friendly); and all types of English-language documents published up to August 2022 were retrieved.

This study considered the three indicators established by Durieux and Gevenois [46]: quantity (productivity), quality (relevance, impact) and structure (connections). Variables such as keywords, annual publications, subject areas, authors, countries, institutions and most prolific countries were analyzed. The results were downloaded in CSV format. Bibliometrix package version 4.0.0 (in RStudio v. 4.2.1) developed by Aria and Cuccurullo [47], and VOSviewer v. 1.6.18 developed by van Eck and Waltman [48] were used to perform scientific mapping by constructing bibliometric networks. The analysis was complemented with the Analyze search results service from Scopus.

Scopus does not produce data for a bibliometric study and, therefore, it may contain errors that will affect the final result [49]. To mitigate errors, two of the authors were responsible for removing duplicate data, correcting errors and adding incomplete information, as appropriate [24].

3. Results and Discussion

3.1. Annual Scientific Production: Classification by Subject Area and Document Type

As shown in Figure 2, a total of 606 documents on environmentally friendly technologies for WW treatment in food processing plants were retrieved from 1972 onwards. In the first three decades the number of studies was very low (50 documents up to 2002). The barrier of 10 documents was surpassed in 2003 with 13 studies, but growth was discontinuous until 2012. Since 2013 there has been a continuous and significant growth. A peak was reached in 2021 with 84 documents published and, so far, there are 57 documents in 2022. The increase in the number of documents is associated with the year in which the United Nations General Assembly established the Sustainable Development Goals (SDGs). Target 6.3 focuses on reducing the volume of untreated WW [50]. Since the adoption of the SDGs in 2015, several studies have been conducted on the importance of WW treatment to achieve target 6.3 [51].

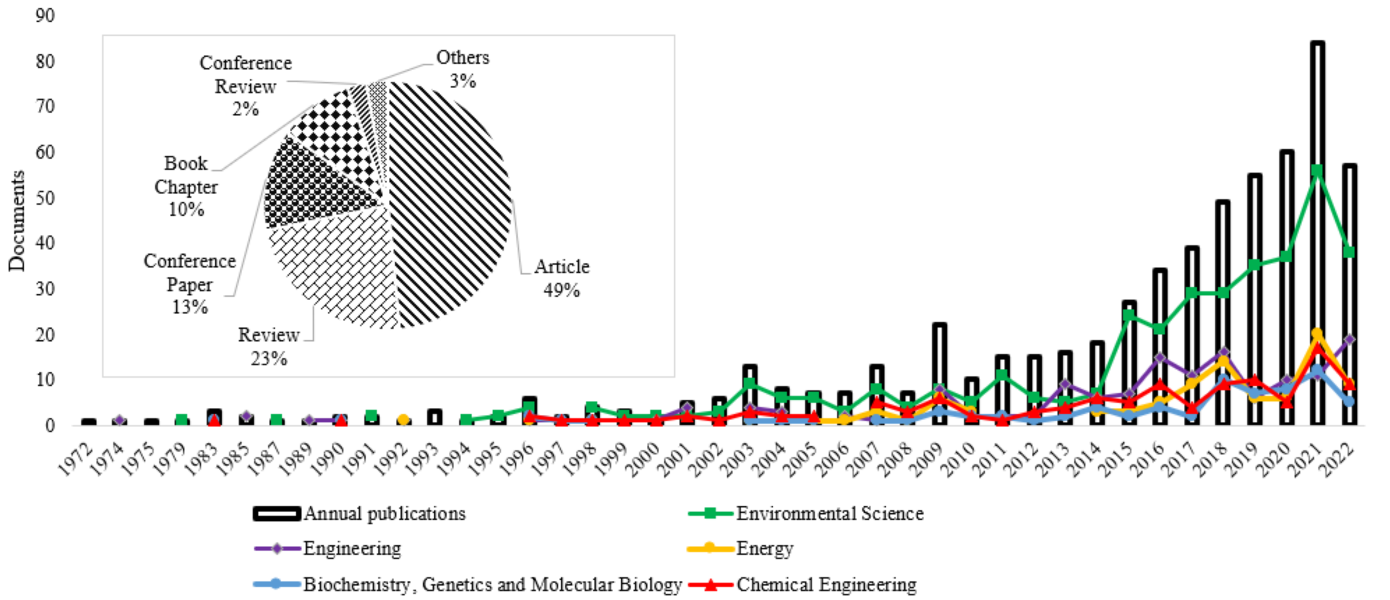

Figure 2. Publications on WW treatment in food processing plants using environmentally friendly technologies.

Price [52] defined three stages of evolution of scientific information about a discipline: precursors, exponential growth and linear growth. The annual production since 1972 fits an exponential trend line with an R^2 value of 0.9056 (data not shown). In this regard, research on WW treatment in food processing plants using environmentally friendly technologies is at the stage of exponential growth. This is mainly due to strict environmental policies and because the population is more environmentally conscious [53].

A document may belong to more than one subject area (category). Figure 2 shows the main subject areas on the use of environmentally friendly technologies for WW treatment in food processing plants. For a better understanding, Gallego-Valero et al. [24] suggested also analyzing the data in percentages. In the early years, no main subject areas are defined. However, in 1996 and mainly since 2003, environmental science has become the predominant area of study with 371 documents (31.156%), followed by engineering, chemical engineering, energy and biochemistry, genetics and molecular biology with 148 (12.395%), 116 (9.715%), 96 (8.040%) and 75 documents (6.281%), respectively. In addition, there are 16 different areas, representing a percentage of 6 to 3%: agricultural and biological sciences > chemistry > materials science > immunology and microbiology; 3 to 1%: earth and planetary sciences > medicine > physics and astronomy > social sciences > business, management and accounting > economics, econometrics and finance; less than 1%: pharmacology, toxicology and pharmaceutics > mathematics > computer science > multidisciplinary > veterinary > decision sciences.

3.2. Main Authors

Table 1 shows the ranking of the authors with the highest contribution to the topic. The field of study still has much to exploit and although there are no prolific authors, Nelson, M. has the largest number of documents published (5). The publications were made in the period 2001–2009; therefore, he is not an author currently focused on the field. His most-cited document focused on the construction of subsurface flow wetlands for WW treatment; concluding that it is economical, environmentally friendly and effective [54]. If the ranking is according to the citation/number of documents ratio, Ngo, H.H. is the main author (about 176 citations per document). He published four documents from 2014 to 2021; he remains current in the field of study. His most cited document is a critical review on the use of agro-industrial wastes/byproducts as natural and low-cost biosorbents for WW treatment; specifically, to remove heavy metal ions, dyes, organics and nutrients [55]. Interestingly, Anon (period 1983–1998) and Chen W.T. (2016 only) published three documents each, but have no citations so far.

Table 1. Authors, countries and institutions with greater participation in studies on WW treatment with environmentally friendly technologies.

Ranking	Name	TD [1]	F [2] (%)	TC [3]	TC/TD
Authors					
1	Nelson, M.	5	0.825	127	25.400
2	Alling, A.	4	0.660	112	28.000
3	Ngo, H.H.	4	0.660	705	176.250
4	Trabold, T.A.	4	0.660	30	7.500
5	Anon	3	0.495	0	0.000
6	Chang, S.W.	3	0.495	346	115.333
7	Chen, W.T.	3	0.495	0	0.000
8	Dempster, W.F.	3	0.495	29	9.667
9	Fatta-Kassinos, D.	3	0.495	325	108.333
10	Guo, W.	3	0.795	400	133.333
Countries					
1	United States	104	17.162	4992	48.000
2	India	76	12.541	1496	19.684
3	China	70	11.551	2131	30.443
4	United Kingdom	39	6.436	1101	28.231
5	Italy	35	5.776	1231	35.174
6	Spain	31	5.116	1102	35.548
7	Malaysia	28	4.620	1186	42.357
8	Australia	26	4.290	1920	73.846
9	Canada	23	3.795	710	30.870
10	Germany	20	3.300	1390	69.500
Institutions					
1	Ministry of Education China	8	1.320	267	33.375
2	Chinese Academy of Sciences	8	1.320	101	12.625
3	University of Technology Sydney	7	1.155	794	113.429
4	University of Chinese Academy of Sciences	7	1.155	102	14.571
5	Council of Scientific and Industrial Research India	6	0.990	63	10.500
6	Institute of Ecotechnics	5	0.825	127	25.400
7	University of Galway	5	0.825	76	15.200
8	Università della Calabria	5	0.825	126	25.200
9	Consiglio Nazionale delle Ricerche	5	0.825	266	53.200
10	Universidad de Granada	5	0.825	162	32.400

[1] TD: total documents, [2] F: frequency: TD/606 (documents retrieved) × 100, [3] TC: total citations.

As an additional fact, the average number of authors per document is 4.056. In short, research in the field tends to be collaborative [44], which implies that it is gaining interest [45].

3.3. Main Countries

The United States is the country with the most documents published (104, Table 1). The most recent document is by Liu et al. [56], who detailed the economic and ecological benefits of using photosynthetic bacteria for WW treatment. The efficiency of this alternative for the recovery of high-value biological resources such as carotenoids, polyhydroxyalkanoates and bacteriocins was highlighted. Australia has the highest TC/TD ratio (73.846). Younas et al. [57] published the most recent document on the use of wetlands for the sustainable treatment of WW, especially for chromium removal.

The collaboration between countries is shown in Figure 3. The top 5 is made up of China, the United States, India, the United Kingdom and Italy with a total link strength (TLS) of 74, 52, 44, 41 and 37, respectively. Established groups can be seen: (a) China, United States, India, Australia, Malaysia, Canada, Egypt and South Korea; (b) Sweden, Germany, United Kingdom and Greece; (c) Spain, Italy, Netherlands, Portugal, France, Brazil and Poland. The only Latin American countries in this list are Mexico (cooperation with the United States (TLS: 2) = China = India = Pakistan > United Kingdom (TLS: 1) = Canada) and Brazil (cooperation with China (TLS: 1) = Spain = France).

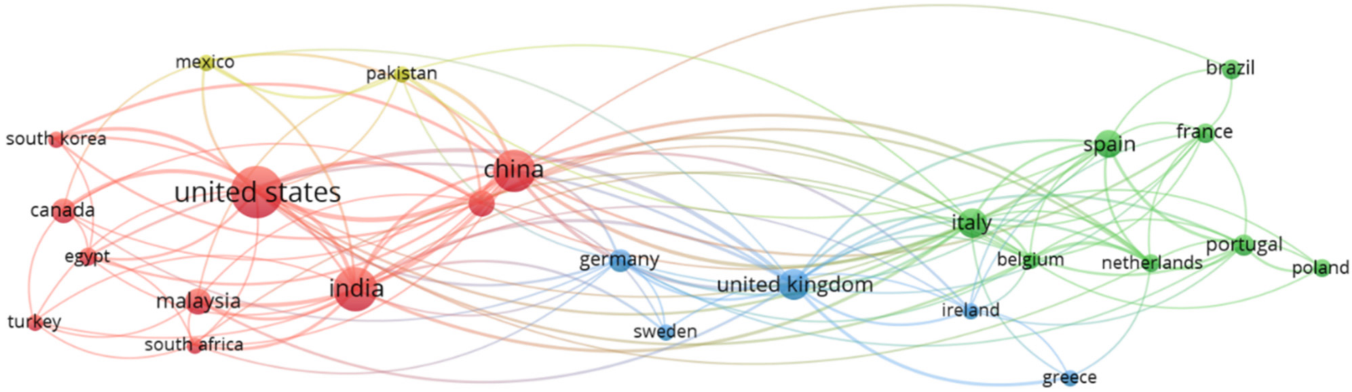

Figure 3. Network visualization map of countries with at least 10 documents.

According to the study by Khan et al. [58], the gross domestic product (GDP), trade and industrialization of each country have a positive and significant correlation with the concern for WW treatment. This is related considering that the United States also ranked first in GDP (2021 data in USD billions): 22,996,100 [59]. Comparing with all the countries in Table 1, the number of documents:GDP ratio is 1:1, 2:5, 3:2, 4:4, 5:6, 6:9, 7:10, 8:8, 9:7 and 10:3; there is a slight correlation. According to data from 2015, in low, lower-middle, upper-middle and high-income countries, WW treatment was carried out in a proportion of 54, 64, 69 and 85%, respectively [60]. This is also associated with the countries in Table 1. According to the World Bank, all countries are high-income, except India and Malaysia (lower-middle and upper-middle income, respectively) [61].

Tuninneti et al. [62] determined that trade is positively associated with the efficient management of water resources. The World Trade Organization [63] classifies countries into four levels according to trade per capita (1: USD 0–500, 2: USD 500.01–2000, 3: USD 2000.01–10,000 and 4: > USD 10,000). India and China are located at the first and second levels, respectively; the United States, Italy, Spain, Malaysia, Australia and Germany are located at the third level; the United Kingdom, Australia and Canada are located at the fourth level. In this context, a single variable does not define the concern and research on WW treatment for each country; multiple factors need to be analyzed.

3.4. Main Institutions

The top 10 institutions in the field of study published 10.066% of the total number of documents (Table 1). Institutions from China predominate (third place with 70 documents); Ministry of Education China and Chinese Academy of Sciences share the first place in the ranking with eight documents published. The most recent document from each institution is by Gao et al. [64] and Huang et al. [65], respectively. The first dealt with the use of cold plasma (ionizing gas) as a simple, environmentally friendly, low-cost and effective tool for disinfecting and removing contaminants in WW. The second study dealt with the impact of WW management on energy, water and the environment. Since WW is treated as waste, the consumption of energy and water is high, in addition to harming the environment. To avoid this, the treatment and reuse of effluents was proposed, in addition to recycling resources. The highest citation/number of documents ratio is by University of Technology Sydney (113.429), which is consistent with it being an institution in Australia, the main country in the same category. The most recent document is by Trianni et al. [53], an interesting study highlighting the boom in research on industrial WW treatment due to stricter environmental policies and greater environmental consciousness. It was concluded that the appropriate technology should be economical and should be chosen according to the influent, characteristics of the area, social factors and regulatory standards.

3.5. Main Journals

To evaluate the journals, we determined (a) quartile (Q) in which they are positioned according to the total number of journals in a specific area; (b) journal impact factor (JIF), citation frequency of the average articles in the last two years.; (c) SCImago journal rank (SJR), scientific influence of the journals according to the number of citations received and the prestige of the journals in which the citations were made [24].

The journals with the most papers (Table 2) are *Science of the Total Environment* (3.465%), *Bioresource Technology* (2.970%), *Water Science and Technology* (2.970%), *Journal of Environmental Management* (2.805%), *Environmental Science and Pollution Research* (2.310%) and *Water Research* (2.310%). All the journals belong to quartile 1 (Q1), except *Water Science and Technology* (Q2), which is also the only one with exclusive open access. These journals published 16.832% of the documents on the research topic. In general, most of the journals belong to Q1 (such as *Chemosphere*, *Journal of Cleaner Production*, *Water*, *Journal of Chemical Technology and Biotechnology* and *Journal of Environmental Chemical Engineering*) and Q2 (such as *Water Environment Research*, *Advances in Space Research*, *Sustainability*, *Ozone Science and Engineering* and *Environmental Technology*); are from the United Kingdom, Netherlands, United States and Switzerland; and published by Elsevier, followed by other major publishers such as MDPI, Springer, John Wiley and Sons, and Taylor and Francis. Likewise, the journals present high quality indicators such as *Water Research* with a TC/TD ratio of 139.286, a JIF of 13.400 and SJR of 2.81. In this context, it can be noted that most of the documents published have a significant level of quality.

Table 2. Main journals in research on WW treatment in food processing plants using environmentally friendly technologies.

Ranking	Journal	Country	Publisher	Q	TD [1]	F (%) [2]	TC [3]	TC/TD	JIF [4]	SJR [5]
1	*Science of the Total Environment*	Netherlands	Elsevier	Q1	21	3.465	930	44.286	10.753	1.81
2	*Bioresource Technology*	United Kingdom	Elsevier	Q1	18	2.970	1574	87.444	11.889	2.35
3	*Water Science and Technology*	United Kingdom	IWA Publishing	Q2	18	2.970	237	13.167	2.430	0.45
4	*Journal of Environmental Management*	United States	Academic Press	Q1	17	2.805	1141	67.118	8.910	1.48
5	*Environmental Science and Pollution Research*	Germany	Springer	Q1	14	2.310	442	31.571	5.190	0.83
	Water Research	United Kingdom	Elsevier	Q1	14	2.310	1950	139.286	13.400	2.81

[1] TD: total documents, [2] F: frequency, [3] TC: total citations, [4] JIF: data from 2021 according to Clarivate Analytics, [5] SJR: data from 2021 according to Elsevier.

3.6. Main Documents and Keywords

This section provides more specific information on advances in the field of environmentally friendly technologies for WW treatment in food processing plants; it also allows trends to be defined. The 49, 23, 13, 10 and 2% of retrieved documents are articles, reviews, conference papers, book chapters and conference reviews, respectively, in addition to others (2%) such as books, notes, errata and retractions. Table 3 shows the five most-cited documents; all are reviews. There are no authors in common and none of the authors are in the Top 10 mentioned in Table 1. For a subjective measure, the average number of citations per year of publication was also evaluated. In both cases, the study by Brenan and Owende [66] occupies the first place and together with the study by Lam and Lee [67] showed information on the importance of taking advantage of the nutrient content of WW to cultivate microalgae. It is presented as a circular alternative since, in parallel, the microalgae purify the water.

Table 3. Most cited documents in the field of study.

Ranking	References	Number of Authors	Year of Publication	Document	Journal	Document Type	TC [1]	TC/Y [2]
1	Brennan and Owende [66]	2	2010	Biofuels from microalgae-A review of technologies for production, processing, and extractions of biofuels and co-products	*Renewable and Sustainable Energy Reviews*	Review	3227	268.917
2	Lefebvre and Moletta [68]	2	2006	Treatment of organic pollution in industrial saline wastewater: A literature review	*Water research*	Review	899	56.188
3	Lam and Lee [67]	2	2012	Microalgae biofuels: A critical review of issues, problems and the way forward	*Biotechnology Advances*	Review	657	65.700
4	Brenn-er et al. [69]	3	2008	Engineering microbial consortia: a new frontier in synthetic biology	*Trends in Biotechnology*	Review	601	42.929
5	Mit-ch et al. [70]	6	2003	N-nitrosodimethylamine (NDMA) as a drinking water contaminant: A review	*Environmental Engineering Science*	Review	579	30.474

[1] TC: total citations, [2] TC/Y: average number of citations per year.

The most-used keywords are shown in Table 4. Groups can be formed with related words: (a) WW treatment, (b) food industry, (c) environmental sustainability, (d) biotechnologies for treatment. At first glance, the trend is the use of biological organisms (plants, algae, microorganisms) for sustainable WW treatment. Further information is provided in Figure 4 where four keyword clusters are visualized. All clusters contain keywords with the denomination of various sustainable and efficient (bio) technologies for WW treatment. Specifically, the red cluster focuses on physical and chemical systems, highlighting different variants of filtration and membrane technology. More detail is shown below.

The yellow cluster focuses on biosorption, a passive process involving adsorption of particles (adsorbate) on the surface of cell bodies (adsorbent) [71]. Biosorption is considered as a biotechnological process with high yield, selectivity and low cost. Natural biosorbents such as marine algae, plants, plankton, and other microorganisms can be used [72]. In the cluster, biosorption and heavy metals can be related. A comprehensive review on the use of food byproducts as heavy metal bioadsorbents for WW treatment was recently conducted [73]. Algae [74] and microorganisms [75] were also reported to have high biosorption capacity for heavy metals.

The blue cluster emphasizes the use of microorganisms and algae for water purification. This cluster also gives signals on the use of biological agents to produce biofuels, ideal for meeting the increase in energy demand by taking advantage of the high and diversified organic load present in the WW generated in food processing as a raw material. Promising results were shown when bacteria, cyanobacteria, fungi, yeasts and microalgae were used for WW treatment and biofuel production simultaneously [76,77]. Microalgae are the most studied because they are versatile; they can grow in WW with low nutrient concentrations and even in unfavorable environmental conditions [78]. However, cultivation and harvesting of microalgae are expensive; therefore, microalgae–microorganism consortia were used successfully, but interactions (positive and negative) are still under study [79].

Table 4. Main keywords used in the documents.

Ranking	Keyword [1]	Occurrence	Ranking	Keyword	Occurrence
1	wastewater treatment	432	11	anaerobic digestion	61
2	wastewater	161	12	water quality	60
3	wastewater management	124	13	bioremediation	59
4	sewage	97	14	biomass	59
5	effluents	92	15	water purification	57
6	sustainable development	74	16	bioreactors	56
7	food industry	67	17	food processing	56
8	waste disposal	62	18	agriculture	53
9	water pollution	62	19	chemical oxygen demand	49
10	environmental technology	62	20	environmental protection	49

[1] Redundant keywords such as waste water (106 occurrences), water treatment (101), water management (72), waste treatment (66), and waste management (63) were omitted; as well as unrelated keywords such as article (124), nonhuman (108), review (68), priority journal (60) and human (54).

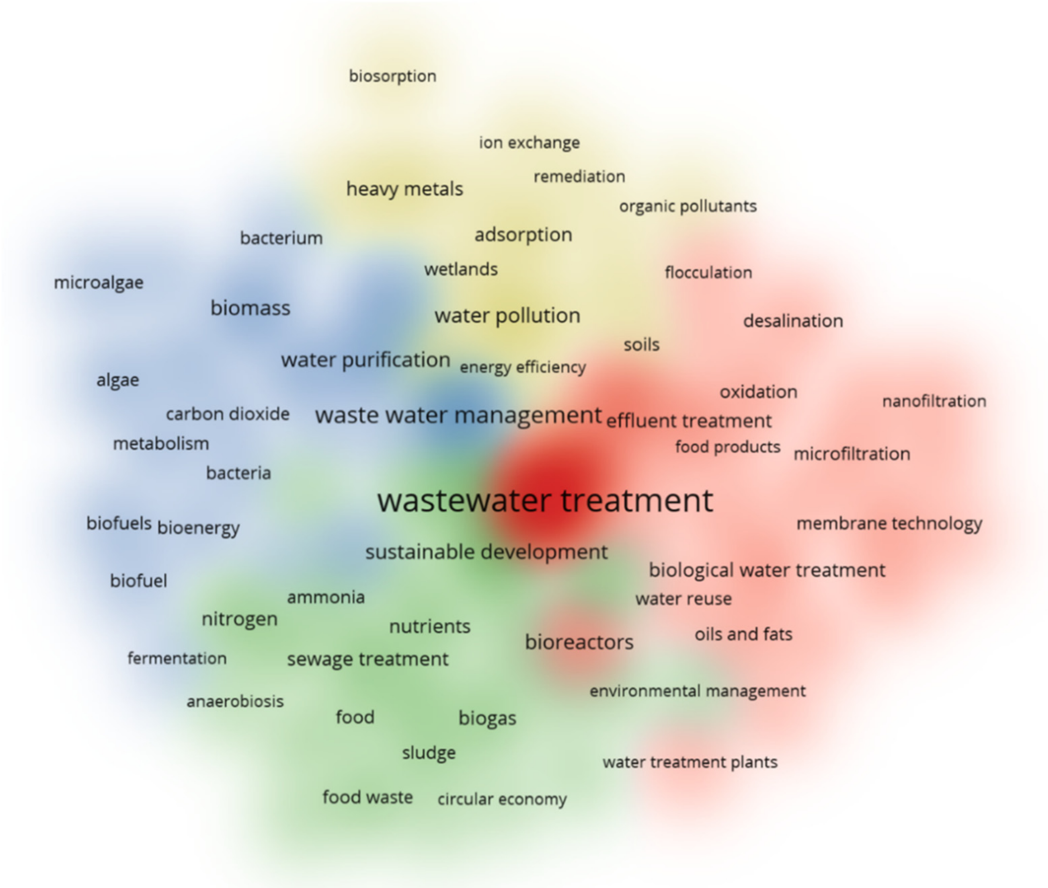

Figure 4. Cluster density visualization map of keywords with at least 15 occurrences.

The green cluster includes keywords related to compounds present in WW such as phosphorus, nitrogen and ammonium. This is related to the fact that WW is a source of energy and resources; nitrogen, phosphorus and carbon can be recycled and reused as valuable resources for a circular economy [80]. On the other hand, ammonia is a common toxic element in WW; therefore, its elimination is essential [81]. The term biogas is related to the blue cluster on bioenergy production to contribute to the circular economy and sustainable development.

Finally, to assess how the field has developed over time, Figure 5 shows the distribution of keywords from 2011 to 2021. The position of the circle shows the average year of keyword usage, and the size determines the frequency. Membrane and filtration technologies were widely used in research conducted from 2010 to 2020. Membrane technology includes microfiltration, ultrafiltration, nanofiltration, reverse osmosis, liquid membrane, etc. [51]. Microfiltration, ultrafiltration and nanofiltration membranes have pore sizes of 0.1–10 µm, 0.1–0.001 µm and 0.5–2.0 nm, respectively [82]. Table 5 shows some characteristics of membrane technologies and Table 6 presents some studies on their use for WW treatment in food processing plants.

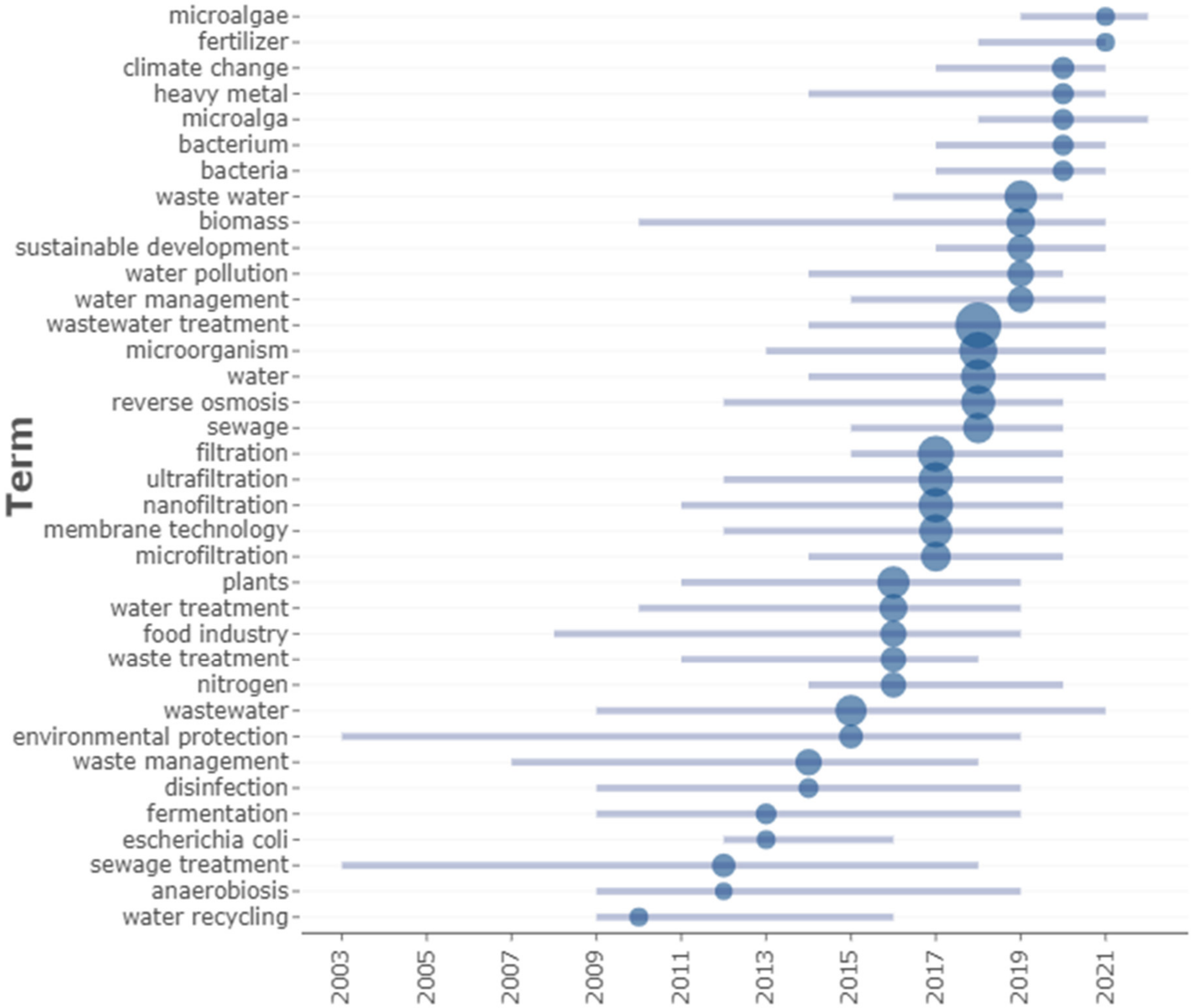

Figure 5. Trend topics of keywords at least 15 occurrences.

Table 5. Most-used membrane technologies for WW treatment in food processing plants. Data from Obaideen et al. [51].

What Substances Do They Retain? [1]	Microfiltration	Ultrafiltration	Nanofiltration	Reverse Osmosis
Water	–	–	–	–
Monovalent ions	–	–	–	+
Multivalent ions	–	–	+	+
Surfactants	–	+	+	+
Oil and grease	+	+	+	+
Suspended solids	+	+	+	+

[1] Retained (+) and non-retained (−) substances.

Table 6. Application of membrane technologies for WW treatment in food processing plants.

Technology	References	Process [1]
Microfiltration	[83]	Margarine
	[84]	Dairy
	[85]	Dairy
	[86]	N.S.
	[87]	Olive oil
Ultrafiltration	[88]	Meat, vegetables and rice
	[89]	Animal proteins
	[90]	Meat
	[91]	N.S.
	[84]	Dairy
Nanofiltration	[83]	Fruit juice
	[92]	Oil
	[93]	Dairy and fruit juice
	[94]	Dairy
	[95]	Dairy
	[96]	Confectionery
Reverse osmosis	[92]	Oil
	[97]	Dairy
	[98]	Olives
	[99]	Wine
	[89]	Animal proteins

[1] N.S.: not specified.

Membrane filtration is efficient, but its use is limited by high investment, operation and maintenance costs; high energy requirements; fouling and/or clogging due to high solute concentrations in the effluent; limited flow rates, etc. [100,101]. Therefore, various biological agents have been used since 2011 (Figure 5) and interest is continuously increasing due to their low cost, versatility, simplicity, renewability and low secondary contamination [38]. Table 7 shows a summary of research related to the topic. The use of microalgae of the genus *Chlorella* is highlighted because of their potential to grow in various WW and take advantage of their nutrients to increase biomass yield [102]. *Chlorella* spp. are widely used for WW bioremediation, mainly for heavy metal detoxification [103].

Table 7. Biological agents used for the friendly treatment of WW in food processing plants.

References	Process	Biological Agent [1]
[104]	Corn	*Rhizopus oligosporus*
[105]	Dairy	*Shewanella oneidensis*
[106]	Dairy	*Lactobacillus pentosus*
[107]	Dairy	Microorganisms (N.S.)
[108]	Dairy	Microorganisms (N.S.)

Table 7. *Cont.*

References	Process	Biological Agent [1]
[109]	Vegetable oil	Microorganisms (N.S.)
[110]	Dairy	*Scenedesmus quadricauda* and *Tetraselmis suecica*
[111]	Snacks of potatoes, nuts, legumes, wheat flour, milk and soya	*Chlorella sorokiniana*, *Scenedesmus obliquus* and *Scenedesmus abundans*
[112]	Mackerel	*Scirpus grossus* and *Thypa angustifolia*
[113]	N.S.	*Trametes versicolor*
[114]	Dairy	Microalgae (N.S.)
[115]	Meat	*Chlorella* sp. UTEX LB2068, *C. protothecoides* UTEX B25, *C. zofingiensis* UTEX B32, *C. vulgaris* UTEX 259, *C. protothecoides* SAG 211, *C. sorokiniana*, *Chlamydomonas reinhardtii* UTEX C-4333, and *Scenedesmus obliquus* UTEX B2630
[116]	Beer	*Pleurotus ostreatus* M2140, *Agaricus bisporus* M7215, *Trichoderma harzianum* CBS 226.95, *Trametes versicolor* M9912, and *Lentinula edodes* M3782,
[117]	Wine	*Chlorella vulgaris* and *Arthrospira platensis*
[118]	Meat	Microalgae (N.S.)
[119]	Dairy	*Chlorella sorokiniana*
[120]	Distillery	*Haematococcus pluvialis*, *Spirulina platensis* and *Chlorella vulgaris*
[121]	Dairy	*Chlorella sorokiniana* SU-1

[1] N.S.: not specified.

4. Conclusions

Food and beverage processing generates a large volume of WW of varied and complex composition; therefore, the use of efficient, ecological and economic treatments is necessary. This bibliometric study revealed a number of findings of interest. First, the field of study is in a stage of exponential growth and there is much to explore; there are no prolific authors. A slight positive association was found between the contribution of countries and their GDP, level of trade and industrialization. Most documents are published in high-impact journals, which also indicates the quality of the research. Mainly, research is focused on the use of biological agents as a simple, cheap and ecological alternative for the treatment of effluents generated in food processing plants; in addition to providing the advantage of recovering the nutrients of interest, giving them a subsequent use and thus establishing a circular economy.

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