BIORESOURCE POTENTIAL OF DUCKWEED IN AQUACULTURE PRACTICES: AN UPDATED BIBLIOMETRIC ANALYSIS THROUGH SCOPUS DATABASE

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DOI:10.5958/2249-7137.2024.00018.8

ABSTRACT

Bioresources are of significance to humans as potential source of raw material, feedstock, for product and energy generation with economic and industrial viability. Duckweed known as 'water lentils', are surface, beneath surface floating plants in fresh and brackish water systems of Lemnaceae family. Duckweedsbestow remarkable bioresource potential to aquaculture practices in terms of sustainable feed, value added production and,energy generation (biofuels) with potential of bioremediation and waste-water treatment. This paper explores bibliometric collection ofvarious works discussing the bioresource potential of duckweed in aquaculture practices.Astute linkages of China, India, US are visualized in terms of publications, citations and total link strength as top three contributors country wise. Organization wiseHenan Province Engineering Research Center, China has maximum documents, citations and total linkage. Central themes observed through keywords and title field depict developing trends on the topic.

KEYWORDS: *Duckweed, Fish Feed, Protein Nutrition, Aquaculture, Bibliometric Analysis.*

1. INTRODUCTION

Aquaculture has contributed largely to global food fish produce and is deemed to be one of the largest sources of animal protein of human diet and nutrition. Aquaculture dependence on fish meal (FM), fish oil (FO) accounts 63% and 81% of their global supplies respectively,particularly with respect to valued farmed carnivorous varieties including salmon, sea bass and sea bream (HLPE, 2017; WRI, 2013; Woodgate et al.,2022). Rising cost of aquaculture feed due to impelled use of FM and FO in diets require search for suitable alternative feed sources that may contribute to sustainable aquaculture growths.Partial or total replacement of FM is plausible with inclusion, chiefly comprising plant ingredients (such as those consisting duckweeds) and insect

meal from black soldier fly (BSF) *Hermetia illucens*.Limiting effects of insect meal have been reported due to low n-3 PUFA and low palatability, digestibility owing to high chitin content and posing negative effects on fish growth (Alfiko et al.,2022; Maulu et al., 2022). Terrestrial ingredients such as plant proteins and plant-derived oils (for example- sunflower oil, soybean oil), for aquaculture can pave way for sustainable productions. Plant proteins with protein content and amino aciddigestibilitysimilar to fishmeal can minimize economic and environmental footprint (Naylor et al., 2009; Pleić et al., 2022). In this respect plant based alternatives such as duckweeds as non-conventional ingredients in aquaculture feeds offer greater promise.Duckweeds are one of the smallest known, fastest growing aquatic macrophytes with large number of globally distributed species. Known for their incremental growth potential duckweeds contribute to higher biomass production within shorter time span (Appenroth et al., 2013). Duckweeds include four genera namely *Spirodela* commonly called as greater duckweed, *Wolffia* (watermeal), *Wolffiella* (consisting common forms mud-midgets, bogmats) and *Lemna*, with grossly thirty seven (Appenroth et al., 2013) reported species. Duckweeds represent efficient nutrient uptake potential for nitrogen and phosphorous with protein content ranging between 30-45% dry matter (Stadtlander et al.,2023).Moreover,high protein amounts in few strains and alternative growth conditions makes duckweed biomass valuable aquafeed ingredient and as human food for direct consumption (Leng et al.,1995; Xu et al., 2021). Atfeed inclusion levels between 15-30%positive effects on growth and feed conversion ratio (FCR) have been reported without affecting survival ratesof fish (Minich & Michael, 2024).Bioresources*are non-fossilized biogenic*materials*for human use as source of food, feedstock, value added products and energy.* Bioresources are the naturally existingrenewable and biodegradable materials considered to besustainable solutions central to bioeconomy (Ingle et al., 2020). Duckweeds bestow remarkable bioresource potential to aquaculture practices in terms of sustainable feed and valueadded production (biochar, bioplastics, biopolymers), energy generation (biofuels such as bioethanol, biogas), with potential of bioremediation and waste-water treatment (Muradov et al., 2014; Baek et al.,2021; Irabor et al.,2022). Present work specifies bibliometric development in terms of literature growth, funding, documentation, citation, keyword trends, authorwise and organization based linkages to investigate time trending expansions on the theme, with potentialof duckweeds in progressing sustainable aquaculture discourse.

2. MATERIALS AND METHODS

2.1 Collation of Bibliometric Information

Bibliometric analysis attempts to provide enhanced understanding of the research backdrop, organization, and interrelationships (NOAA, 2015). Scopus database was searched in '*All fields*' tabwith input term '*duckweed bioresource in aquaculture'*on date 19/9/2024.Citation report of documents with cumulative h-index and total citations of publications was generated.Bibliography, funding, keyword and abstract information were downloaded in CSV file format for further analysis.

2.2 Bibliometric Data Analysis

Bibliometric data analysis is carried by VOSviewer software (version 1.6.20)for construction and elucidation of bibliometric links. Bibliometric network visualization envisages co-authorship country, author, organizations,keyword co-occurrence and title field analysis.

3. Results and Discussion

3.1 Document Coverage and Citations Analysis

Document coverage accounts information pertaining to publication type, number, authorship, subject area, country, organization and funding sponsors. Citation analysis considers total citations as well as year wise citations received by the published works.

1,524 documents were obtained on the search topic '*duckweed bioresource in aquaculture'* with cumulativeh-index of 104 and total citations 52,932. Maximum published documents (n=225) were in the year 2022 followed by 208 works in 2023. Year-wise rising trend in publications show escalation in received citations,with maximumcitations documented in 2023 as depicted inFig.1.

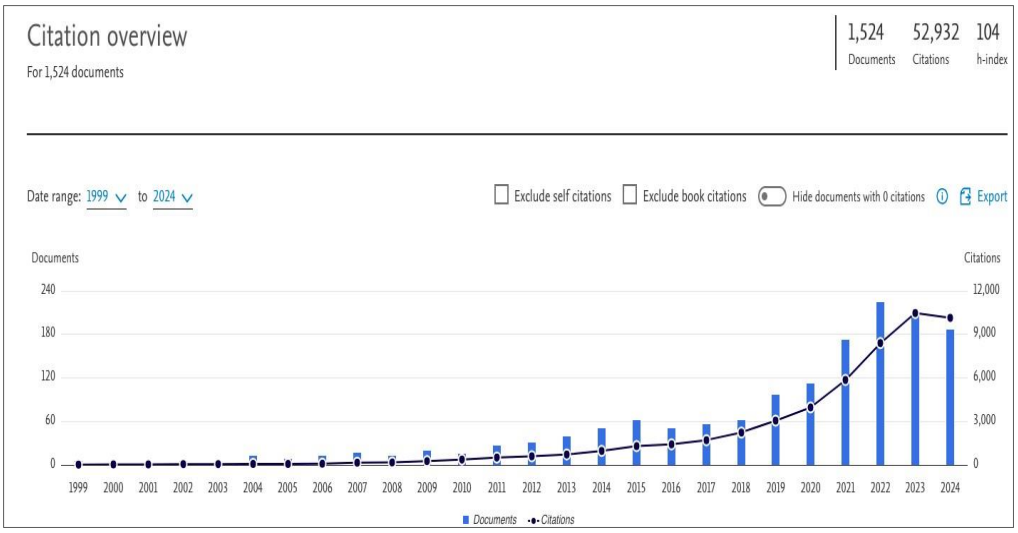

Fig.1.Year-wise document and citation overview (Source: Scopus,2024)

*Articles*have highest count n= 941 accounting 61.7% of total publication types, followed by *review* (n= 348, 22.8%), *book chapter* (n=192, 12.6%),*conference paper* (n=24, 1.6%) and*book* (n=19,1.2%), shown in fig.2.

Top five areas addressing the subject, as shown in Table 1, are environmental science with 29.9% contributions, agricultural and biological sciences (18.6%), engineering (8.4%), energy (6.9%), and chemical engineering (6.9%).

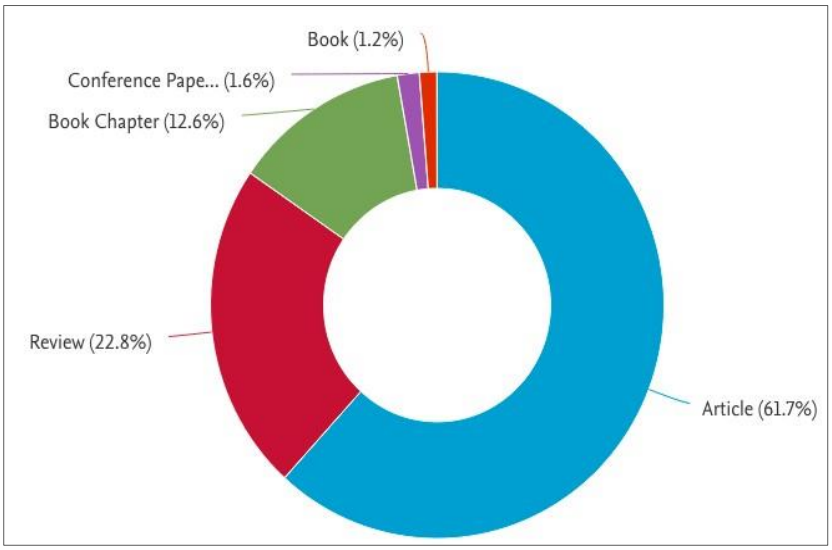

Fig.2.Type of published works on duckweed bioresource in aquaculture (Source: Scopus, 2024)

Table 1: Number of documents in top five subject areas on duckweed bioresource in aquaculture (Source: Scopus, 2024)

Subject Area	**No. of documents**
Environmental science	889
Agricultural and biological sciences	553
Engineering	251
Energy	206
Chemical engineering	205

Zhao H. is the most prolific author with maximum documented research items,n=19. Fang Y., Appenroth K.J., Ray A.K., Abdullah S.R.S., have 15,14,13,12 publications respectively. Fig. 3 provides top ten most prolific authors in terms of number of publications on the theme.

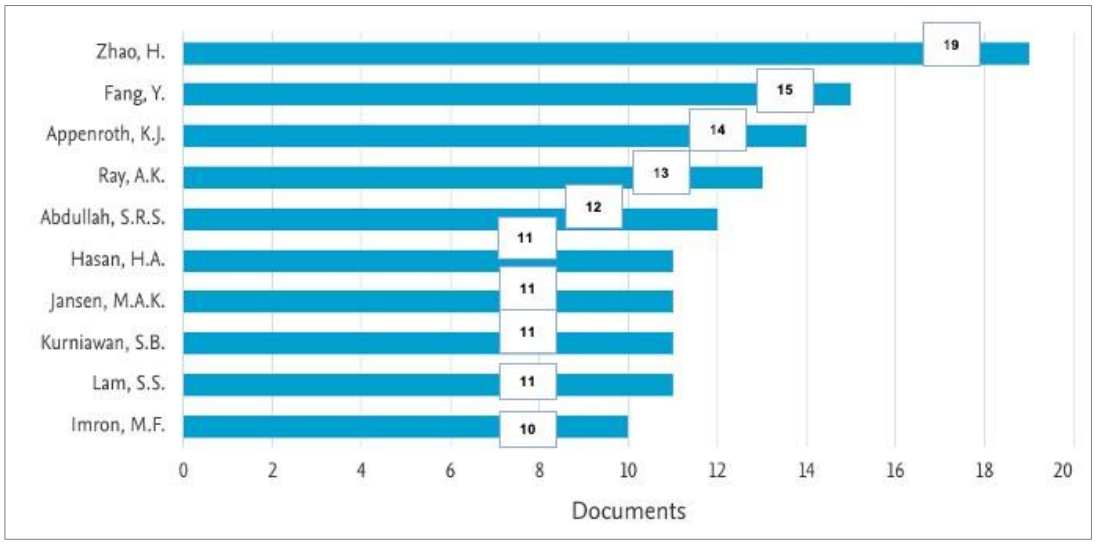

Fig.3. Top ten author publications on duckweed bioresource in aquaculture (Source: Scopus, 2024)

Country wise highest 356 works are contributed from China. Among top 10 countries addressing the theme, India has second to highest number of documents 322; followed by documentations from US (150), Malaysia (85), Egypt (68), Brazil (61), Germany (55), UK (54), Australia (53), and Netherlands(44) as can be seen in Fig.4.

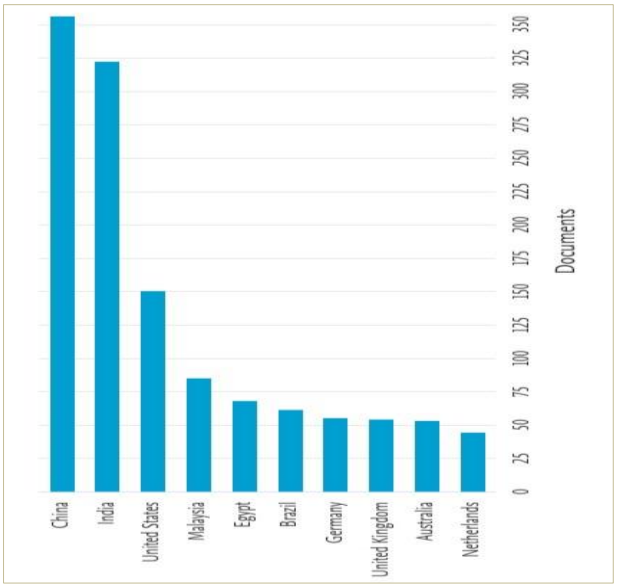

Fig.4.Top ten country publications on duckweed bioresource in aquaculture (Source: Scopus, 2024)

Top 10 prolific organizations in terms of document count on the subject,are listed in Fig.5.These include three from China- Chinese Academy of Science, Ministry of Education of the Peoples' Republic of China, and University of Chinese Academy of Sciences. The Indian Council of AgriculturalResearch, India;University Kebangsaan Malaysia, Malaysia; Wageningen University and research, Netherlands; North Carolina State -NC State university, US; ICARCentral institute of fisheries education, India; Visva Bharti University, India are amongst the topmost contributors on the topic. Notably, Chinese organizations haveoutstanding contribution, extensively exploring resource potential of duckweeds in aquaculture practices.

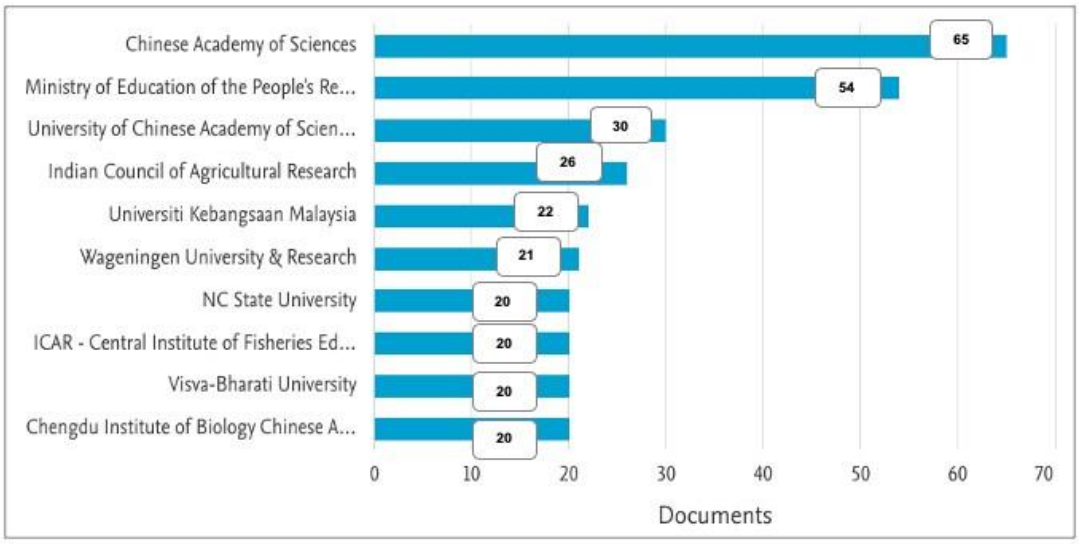

Fig.5. Top 10 organizations contributing on duckweed bioresource in aquaculture (Source: Scopus, 2024)

Top five funding sponsors on the research topic listed in Table 2 are National Natural Science foundation of China, National key research and development program of China, European Commission, Ministry of higher education, Malaysia and Chinese Academy of Sciences.

Table 2: Top five funding sponsors on the research topic (Source: Scopus, 2024)

Rank	Funding sponsors	Documents sponsored
1	National Natural Science Foundation of China	138
2	National Key Research and Development Program of China	44
3	European Commission	39
4	Ministry of Higher Education, Malaysia	35
5	Chinese Academy of Sciences	32

Top five journals publishing on the topic (Fig.6) are Bioresource technology (Elsevier's) with largest number of '51' published workssince 1992,followed by Science of the Total Environment (Elsevier's) '45' documents, Environmental Science and Pollution Research(Springer-Verlag

GmbH Germany, Springer Nature)'33', Journal of Environmental Management (Elsevier's) '30', and Chemosphere (Elsevier's) '30'.

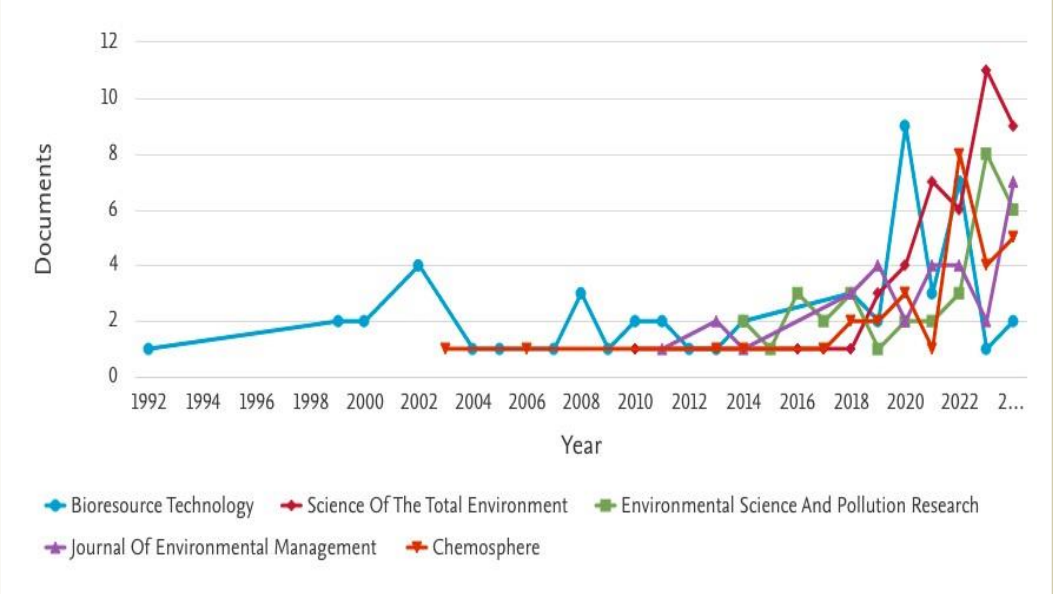

Fig.6. Year-wise documents in top five publication titles on duckweed bioresource in aquaculture (Source: Scopus, 2024)

3.2 Bibliometric Network Analysis

Bibliographic network investigates and visualizesconnectionsgenerated amid publications on the basis of authorship, citations, commonkeywords, specifying semantic and citation networks as well as research collaborations among authors, organizations and countries.

3.2.1 Co-authorship as per countries

Region based co-authorship links 110 countriesaccording to threshold criteria.Of these8 were filtered out due to no connection, giving 102 connected country clusters. From these 102 countries, largest set of 97 belonging to 14 clusterswere connected.

Of the top 5visualized clusters in Fig. 7., largest cluster group includesChina, Congo, Rwanda, Belarus, and Slovenia. Second largest cluster includes India,Australia, Indonesia, Japan, Norway, South Korea,Tanzania, and Zambia. Third largest clustering countries are US,Mauritius, and Nepal.

Fourthgrouping includesMalaysia, Cameroon, Cuba, Ecuador, Iraq, Kenya, Libya, Libyan Arab Jamahiriya, Mexico, Morocco, Nigeria, Peru, and Sudan. Fifth largest clustering is among UK, Austria, Israel andQatar. Clearly China, India, US, Malaysia and UK aretop 5 countries as per total linkage intensities with other countries (table 3). Additionally, China, India, and US also are among top three countries based on documents and accrued citation counts.

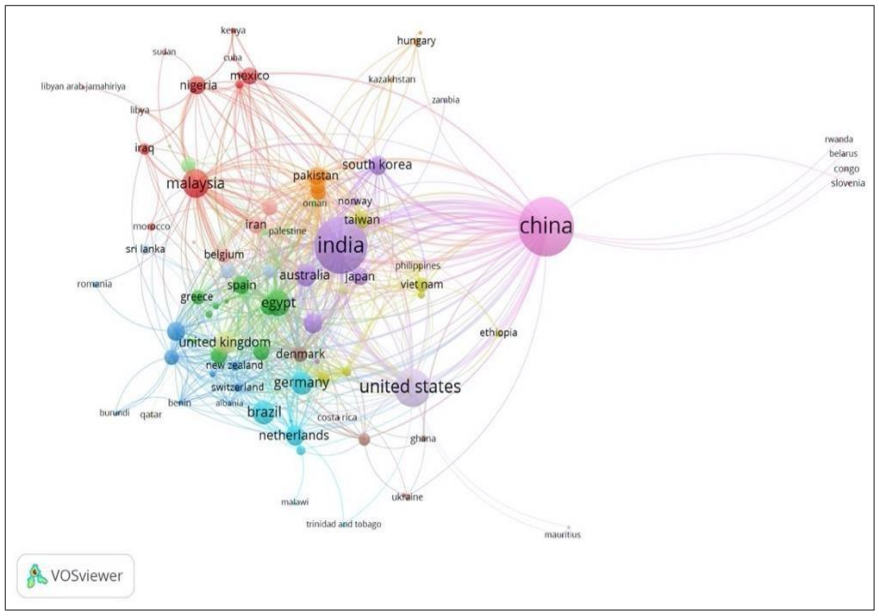

Fig.7. Co-authorship as per countries as per overall link strengthon duckweed bioresource in aquaculture (Scopus, 2024)

Table 3: Top ten countries ranked as per overall link strength(Source: Scopus, 2024)

Rank	Country	No. of documents	citations	Total link strength
I	**China**	356	11882	250
II	**India**	321	11853	220
III	**US**	150	7262	174
IV	**Malaysia**	85	2563	121
V	**UK**	53	2963	94
VI	**Australia**	53	2185	92
VII	**Egypt**	68	4601	92
VIII	**Germany**	55	2119	88
IX	**South Korea**	38	1510	72
X	**Denmark**	25	967	71

3.2.2 Co-authorship organizations

3,946 organizations have co-authorship connections. From these,1000 connected organizations having greatest link strength were selected.Largest set of 106 linkagesarefinally visualized (figure 8). Henan Province engineering research center for biomass value-added products, School of Forestry, Henan Agricultural University, Zhengzhou, China has maximum fivedocuments accumulating 171 citations and highest link strength of ‘39’(table 4).

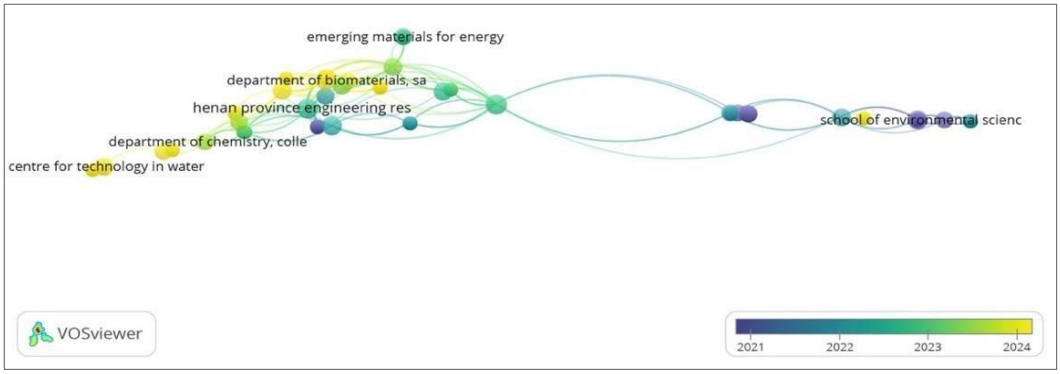

Fig.8. Organization co-authorship on duckweed bioresource in aquaculture

(Source: Scopus, 2024)

Table 4:Top ten organization co-authorships ranked as per overall link strength
(Source: Scopus, 2024)

Organization	Documents	Citations	Total link
henan province engineering research center for biomass...	5	171	39
department of chemical engineering and materials scien...	3	75	34
higher institution centre of excellence (hicoe), institute of ...	3	27	34
department of biomaterials, saveetha dental college, sav...	3	29	33
higher institution centre of excellence (hicoe), institute of ...	5	52	30
department of mechanical engineering of agricultural ma...	3	36	29
biofuel research team (brteam), terengganu, malaysia	2	29	27
university of chinese academy of sciences, beijing, 1000...	17	510	26
aarhus university, department of bioscience, arctic resea...	4	146	23
aarhus university, department of ecoscience, frederiksb...	1	27	21

3.2.3 Co-authorship as per authors

Out of total 6,243 authors, the largest set of connected authors is that of 241.Author linkages are represented in 16 discrete clusters.Fig. 9 visualizes co-authorships of authors based on total link strength (TLS). Zao Hai in red cluster has highest collaborations with TLS of 94, seconded by Fang Yang with 348 citations and TLS= 84.Table 5 elaborates on top 10 co-authorships as on the basis of TLS.

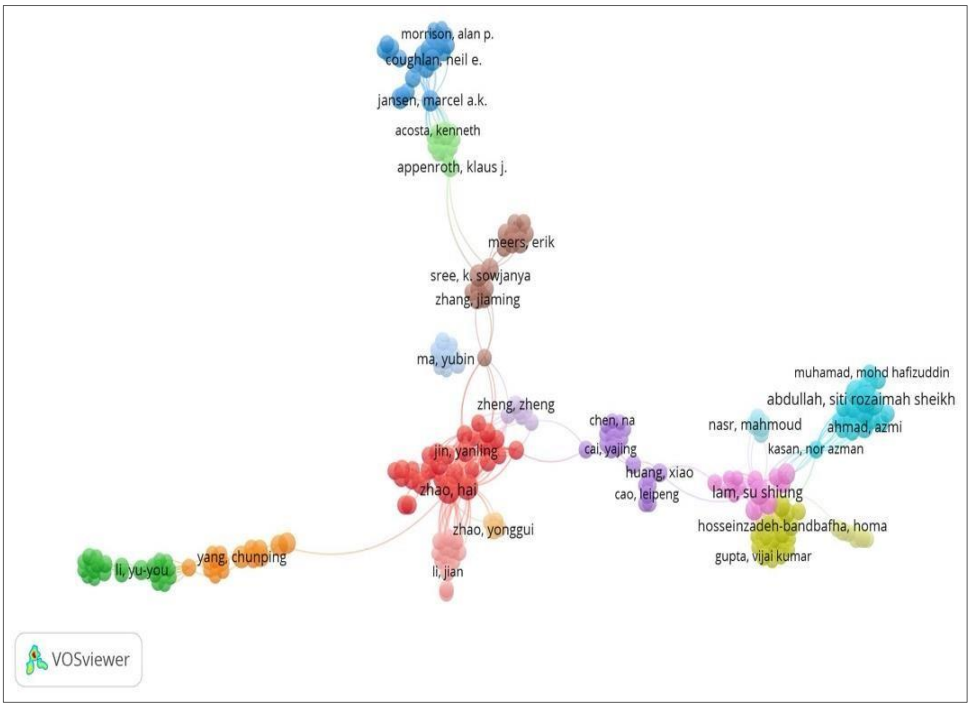

Fig.9. Co-authorship author according to total link strength on duckweed bioresource in aquaculture (Source: Scopus, 2024)

Table 5: Ten topmost author co-authorships as per TLS on duckweed bioresource in aquaculture (Source: Scopus, 2024)

Author	Documents	Citations	Total link strength
zhao, hai	18	575	94
fang, yang	14	348	84
abdullah, siti rozaimah sheikh	14	492	67
kurniawan, setyo budi	11	483	62
lam, su shiung	11	261	58
imron, muhammad fauzul	10	414	57
hasan, hassimi abu	11	395	54
sonne, christian	7	191	49
othman, ahmad razi	8	349	48
peng, wanxi	6	202	43

3.2.4 Co-occurrence of keywords

A total of 10,367 author keywords aregenerated, from these 1,000 with greatest TLS are selected. After exclusion of 4 keywords that did not meet the criteria, 996 keywords are filtered these belongto 6 discrete clusters (Fig.10).

Yellow cluster isrepresented by sustainability and sustainable fuels, “circular economy”, “food waste”, “biogas”, “bio-energy”, “biofuel”, “technology”, “recycling”, “life cycle”;

Red clusterhas relatedness to ecotoxicology, contaminants and health risks, consisting included terms as - " humans", "water pollutant", "ecotoxicology", "pesticide", "plastic waste", "heavy metal", "atrazine", "amoxicillin";

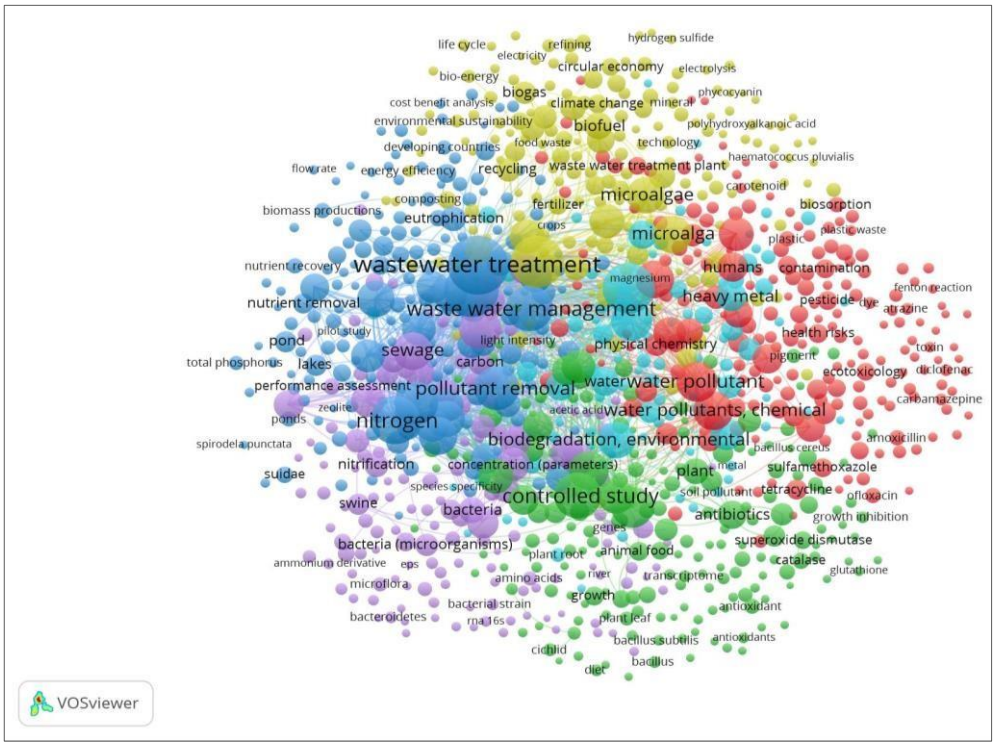

Fig.10. Author keywords according to total link strength on the theme (Source: Scopus, 2024)

Blue cluster is related to "waste water treatment", "eutrophication", "lakes", "ponds", "nutrient removal", "nutrient recovery", "nitrogen", "carbon", "total phosphorous";

Turquoise clusterhas terms " heavy metal", "magnesium", "water";

Green clusteris centralized on study of antioxidant potential and growth effects - terms comprising cluster are "controlled study", "plant", "plant leaf", "antioxidants", "growth", "superoxide dismutase", "catalase", "glutathione", "growth inhibition", "diet", "transcriptome"; **Purple cluster**is thematized by key terms"microflora", "bacteria", "Bacteroidetes", "sewage","nitrification","genes", "bacterial strains" defining association of bacterial flora to duckweeds.

Clearly waste water treatment, management; heavy metal; pollutant removal; human; biodegradation; biofuels, are the central themes among these discrete clusters.

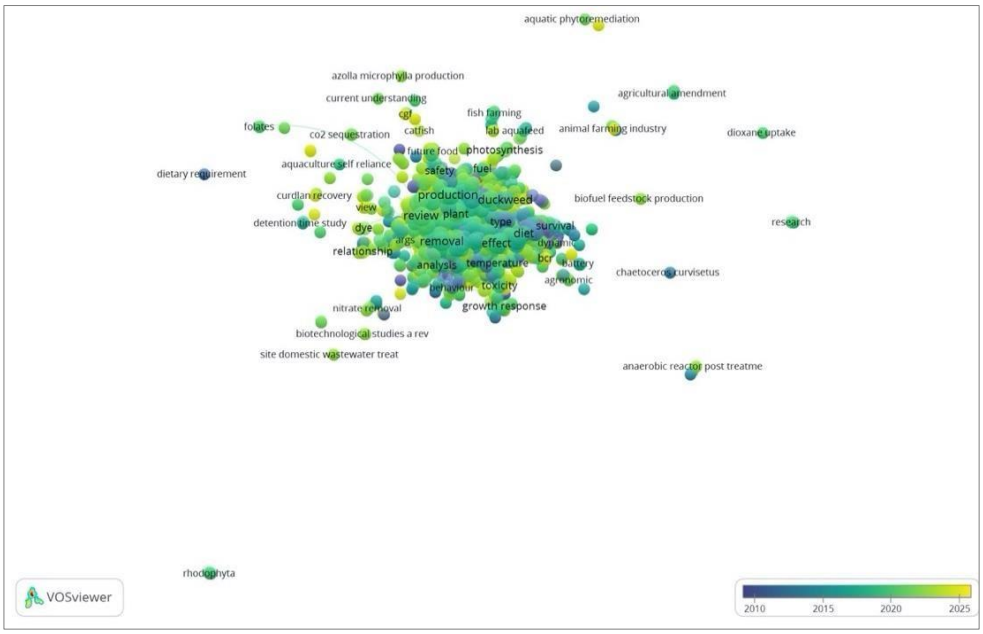

Fig.11. Title field as per occurrence on the topic (Source: Scopus, 2024)

Title field provided 4,280 terms, with 3,937 largest connected set of items, linked among 110 clusters. Prominent clusters focus on duckweed as 'sustainable feed source' with terms in common cluster as 'health food', 'bioeconomic value addition potential', another cluster links duckweed to 'algal biomass', 'microalgae chlorella' and spirulina, and commonality to 'plant origin' 'black soldier fly' as 'alternative source' of feed along with process technologies for 'methane production', 'bio-methanation' indicating bioresource potential.

CONCLUSIONS

Sustainability in aquaculture can be achieved by using equitably sustainable food sources in feed compositions. Feed is a source of nutrients and energy, fundamental for growth, reproduction, and fish health (NRC, 1993). Nutrient profile of aquafeed determines fish welfare and consequent consumer health. In this aspect careful selection of feed alternatives should be done taking into account for protein content as essential nutrient. Plant based feed alternatives derived from duckweeds provide great promise to aquaculture sustainability extending its resource potential in aquaculture practices. Strong linkages of China, India, US are visualized in terms of documents published, citations and total link strength as top three contributors country wise.

Bioresource technology (Elsevier's) has highest number of published works. Author wise Zhao Hai has maximal TLS; while Henan Province engineering research center for biomass valueadded products, China has maximum documents, citations and organization wise TLS. Time trending growth in publications as well as shifting developments in keyword and title field useof terms including, *alternative source; bioeconomy; circular economy; waste water treatment*suggestincreasing interest in the discourse to harness potential of duckweed biomass in sustainable aquaculture growths.

Declaration-

There is no financial and non-financial support received and there is no conflict of interest for the publication.

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