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Global Viewpoint on Cultured Meat: A Bibliometric Assessment from 1952-2023

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Abstract: This study aimed to describe the global outlook of research publications on cultured meat using bibliometric assessment approach from 1952-2023. A total of 1108 research articles were collected from Scopus data archive with average citations per doc and co-authors per document ratio of 28.74 and 4.46. The results of focus for this study of discourse include author key words, keyword plus, leading authors in the discipline, top nations in terms of articles and citation numbers, leading organizations in the discipline, top leading journal sources as well as trending topics among others. The result showed that scientific research on cultured meat over the years was correlated to the annual increase in outputs of articles (R^2 = 0.3905; y = 0.8224x-14.628), which is indicative of growth in number of articles as the year increases. China topped the first position with respect to article publications (n = 145). While USA, Brazil and South Korea were in the second, third and fourth (n = 116; n = 59; n = 45) positions, respectively. In addition, China, UK, USA and Brazil were the leading nations (n = 25; n = 21; n = 20; n = 20) with the highest number of multiply country publications (MCP), respectively. The trending topics from author keywords in this discipline include cultured meat, artificial meat, cell-based meat, *in vitro* meat, and cellular agriculture among others. Scientifically advanced and economically buoyant nations are more involved in research on cultured meat when compared to developing countries. Scientific publications initially appeared to concentrate largely on technical aspects (large production) of cultured meat but more recently on health perspectives, consumer's acceptance, as well as sustainability of production. Conversely, the potential environment-friendly implication of this innovative food are now investigated thereby suggesting the future research of this discipline in line with public health concerns thereby proffering a better clarity for practical implications for government and stakeholders policies.

Keywords: Scientometric, *in vitro* Meat, Food Security, Sustainability, Trending Topics, Public Health

Introduction

The geometric increase of meat and meat products' consumption globally in recent times has been prodigious. At the moment, the general global average meat consumption is pegged around 42.9 kg per capita, with industrial nations consuming about 76.1kg per capita, while developing nations consume an estimate of 33.6 kg, accordingly (Falowo *et al.*, 2022). Conversely, there is a strong indication that meat and meat products' consumption will double by the year 2050 (Chriki and Hocquette, 2020). This is due to the constant rise in human population. The rate of consumption of meat and meat products has been projected to continue to grow geometrically across the globe in the coming years as human population grows (Tobler *et al.*, 2011; Chriki and Hocquette, 2020).

Report from the Food and Agriculture Organization of the United Nations (FAO), has shown that the world human population is projected to reach 9.5 billion in few years from time (Song *et al.*, 2024). The implication of this report is that, more than 70 % of alternative protein source will be required to cushion the effect of human population growth and to accomplish food as well as nutritional demands of people (Sexton *et al.*, 2019). However, among the several novel dietary needs, animal protein source (meat) has grown significantly in total as well as per capita consumption globally (Godfray *et al.*, 2018; Tuorila and Hartmann, 2020). Sadly, evidence have shown that the present meat production system to meet the growing need for meat consumption cannot be sustained (Song *et al.*, 2024). This situation has thrown open the need for farmers, scientists, researchers and other stakeholders to explore other alternative means of increasing meat production that will alleviate societal concerns without compromising sustainable consumption of meat (Henchion *et al.*, 2017; Kappenthuler and Seeger, 2019; Onwezen *et al.*, 2021). Cultured meat appeared to have emerged as a proposed solution to these challenges (Ismail *et al.*, 2020). Scientists perceived cultured meat as having potential advantages for societal acceptance, animal welfare, as well as human health benefits when compared to other protein food source for humans(Post *et al.*, 2020).

Cultured meat production is an aspect of meat science that emerged from regenerative tissue engineering based on precursor of animal cell culture (Fernandes *et al.*, 2019). This means that the production process of cultured meat takes place entirely in the laboratory via an *in vitro* cultivation of stem cells gotten from the cell tissue of animal muscle (Post, 2012). Several terms have been used to describe this type of non-conventional meat production namely; “synthetic meat” (Marcu *et al.*, 2015), "artificial meat" (Bonny *et al.*, 2017; Sodhi, 2017), "*in vitro* meat" (Mattick *et al.*, 2015; Wilks and Phillips, 2017; Acevedo *et al.*, 2018), "laboratory meat" (Galusky, 2014), “ cultivated meat” (Chriki and Hocquette, 2020), just to mention a few. Meanwhile for this study, the word “cultured meat” is retained. In addition, the science of cultured meat is multi-disciplinary in nature. It integrates the process of cellular agriculture which is focused on developing products of animal origin with little or no involvement of the life animal itself (Stephens *et al.*, 2018b). In addition, the concept of cultured meat cuts across the industrial context of biomedicine and agrifood to a new concept of food biotechnology (Enrione *et al.*, 2017).

It is clear that quite a number of research work on cultured meat have been carried out over the years (Falowo *et al.*, 2022; Wang *et al.*, 2023; Song *et al.*, 2024; Xie *et al.*, 2024) for the purpose of increasing meat availability and sustainability. Howbeit, it is very rare to come across publications that have employed bibliometric method to describe the global status and trends on the different research works as relates to cultured meat. Bibliometric analysis in any study presents a unique research approach that allows the use of systematic mathematical permutations to review global research status of a particular scientific discipline and how they are ranked according to nations, institutions, and research authors on the world level (Zou *et al.*, 2019). Bibliometric evaluation is an important stratagem that again help to understand research directions and article outputs of a particular niche area (Ellegaard and Wallin, 2015).

Furthermore, the approach of bibliometric assessment helps to determine most relevant papers within a research discipline by calculating their impact based on the number of times that they are cited and their global h_index score (Ahmad *et al.*, 2019). The art of cataloguing the most cited papers of a research discipline is very beneficial in finding knowledge gaps, which may apparently help to move the research field forward in a progressive direction (Varela *et al.*, 2018). The profile of most cited paper in a research discipline can further be utilized as a guiding yardstick for growing scholars and emerging scientists to follow (Shuaib *et al.*, 2015; Azer and Azer, 2016). The present study will further help to create academic profile capable of promoting future lead-way for research discipline of the present subject of discourse. These details are expected to be useful to policy makers as well as other stake-holders in tackling the issues around cultured meat production, consumption, acceptance, quality and sustainability in the long run.

Another important aspect of bibliometric study in a particular discipline is that the outcomes can help scientist identify advances in the research domain, as well as network with potential collaborators in the future and target journals for publishing their research work (He *et al.*, 2020; Wang *et al.*, 2023). Therefore, the present study conducted a bibliometric evaluation of research publications related to cultured meat which were published from 1952 to 2023. The research condition for this study were summarized from the viewpoints of publication time, research organizations, number of country publications, source of journals, keywords among other indices.

Materials and Methods

Bibliographical Data Used

A search approach the accommodated articles that aligned with the present subject of investigation with the slightest false-positive out-come was employed by browsing several articles on cultured meat research as relate to food in order to streamline this study with the correct keywords to the present subject matter. This kind of approach have previously been utilized in other study for bibliometric investigation (Fesseha *et al.*, 2020). The study was done using the search keyword string “OR” in the information source titles, abstracts and keywords to pull all the synonyms for “cultured meat” covered by Scopus from 1952-2023. Boolean permutations “OR” was used in the search in order to limit the scope of the outcomes required for this study. The search query that was covered for this study in Scopus was: (TITLE-ABS-KEY("healthy meat" OR "slaughter-free meat" OR "in vitro meat" OR "vat-grown meat" OR "lab-grown meat" OR "cell-based meat" OR "clean meat" OR "cultivated meat" OR "synthetic meat" OR "clean meat" OR "artificial meat" OR "cell cultured meat" OR "cultured beef" OR "cultured beef" OR "cultured chevon" OR "cultured mutton" OR "cultured pork" OR "cultured chicken") AND (LIMIT-TO (DOCTYPE,"ar")). From the initial data search, all collected articles including research articles, proceedings, book chapters, reviews, technical notes were gathered in the Scopus datasets from 1952 to 2023. However, every other literatures, apart from research articles were left out for analysis in order to reduce to the barest minimum any form of ambiguity during analysis of the retrieved data. The total number of articles utilized for evaluation in this study was 1108 from the initial aggregate of 1210 articles.

Inclusion Criteria

The data for investigation for this study were collected from the Scopus bibliographical dataset because Scopus is well-known for its broad coverage of scientific research publications (Baier-Fuentes *et al.*, 2020). Furthermore, Scopus is known to be very suitable, extensive as well as easy to use in terms of search and analytical functions for this kind of investigation (Felices-Rojas *et al.*, 2023). Although there are other datasets such as Google scholar, Web of Science (WoS) and PubMed, but Scopus best fit the intention of the present study as it well captured relevant articles for analysis (Yang *et al.*, 2022). Again, the choice of using Scopus for this study, fulfilled the purpose for the data search and outcome of the result for this work. Furthermore, the general agreement for the use of a single database (such as Scopus) for analysis bibliometric studies is broadly approved because of the complexities of doing this kind of study with multiple databases which may lead to loss of some vital publications in the course of coding and mathematical permutations the combination of data from several databases (Sweileh, 2020).

Search Method for Data Collection

The present study employed the following inclusion yardstick for its bibliometric evaluation.

a. Original peer-reviewed articles on research study done on cultured meat
b. Articles published online in Scopus database between 1952 and 2023

Exclusion Criteria

The exclusion yardstick for this study includes:

a. Unpublished articles
b. Unrelated articles
c. Technical notes, review literatures and errata documents
d. Publications involving plagiarism and retracted manuscripts; and
e. Articles not retrieved from Scopus dataset during the studied period

Previous studies have also used this type of approach in data gathering for inclusion and exclusion of undesirable papers in bibliometric analysis (King *et al.*, 2018; Fesseha *et al.*, 2020). The inclusion and exclusion of data for this study is further explained in Figure 1.

Bibliometric Analysis of Retrieved Data

Selected data from Scopus dataset were analysed with the R-Studio (version 4.3.0. 2023-04-21 ucrt) software package for analysis (Aria and Cuccurullo, 2017). All data were transferred into R-Studio software before they were analysed and results visualized. The bibliometrix R-package was also utilized (R-project web interface in Biblioshiny) to describe the results comprising of citation analysis, performance of single authors and countries, leading keywords in the discipline, and intellectual networking by top leading researchers, nations, and institutions in the discipline of discourse. The mathematical permutations for the afore-mentioned networking is as follows;

$$\text{Networking (N)} = O \times T^P$$

Where, the letter "N" represents Networking; "O" gives a bipartite composite matrix of research publications × attributes (e.g. nations, keywords, citation numbers, institutions, keywords plus, and publication numbers). The letter "N" further symbolizes the symmetrical matric of $N = T^P$.

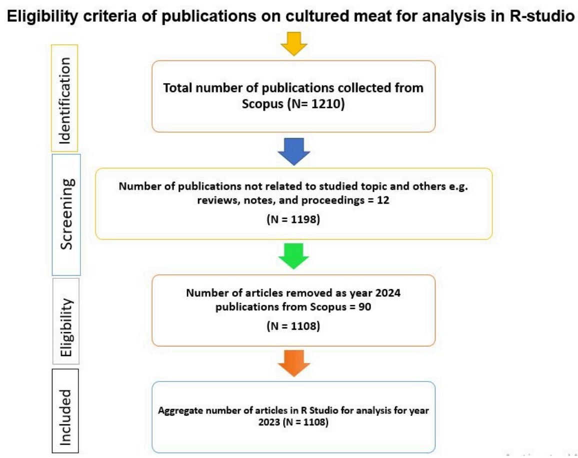

Fig. 1: The inclusion and exclusion of publications on cultured meat from 1952 – 2023

Results

A total number of 1108 research publications between 1952 – 2023 were analysed for the present study. The breakdown of the analysed documents are described in Table 1. The number of authors involved in research work on cultured meat during the studied year of discourse were 3836, meanwhile the number of single authors were 94. There were 4.64% co-authors per document, and 20.22 % global co-authorships. The aggregate number of citations per document is 28.74 %, while the yearly growth rise is 7.29 %. Figure 2 described the polynomial metric fitting curve for this study. This analysis depicts the yearly growth in article numbers and citations of the present study with a positive correlation (R = 0.3905; y = 0.8224x – 14.628) between the cumulative number of publications and the years of research in cultured meat from 1952-2023. The result in Figure 2 further showed a trend in article publication with some years having zero research outputs. Howbeit, there was an appreciable rise in research publications on cultured meat from 1982 (n =

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10) to 2023 (n = 184). The yearly growth of publication of articles is 7.29 %. The highest number of article outputs on the subject matter of discourse was recorded in 2023 (n = 184).

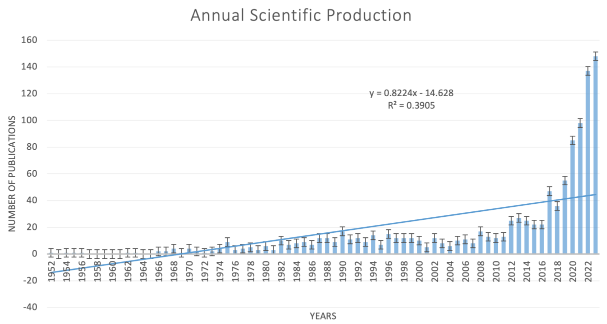

Fig. 2: Yearly number of publications on cultured meat research from 1952 to 2023

Results in Table 2 showed outputs of leading as well as most productive nations involved in research on cultured meat as food in relation to citation and publication numbers. China emerged as the top leading nation in terms of publication numbers (n = 145). The other top leading nations were USA (n = 116), Brazil (n = 59), South Korea (n = 45) and Spain (n = 41), respectively. Meanwhile, there was a position shift in raking with respect to the number of citations among nations globally. UK was ranked in the first position (n = 3634) for highest number of citations followed by USA (n = 3232), China (n = 1857) and Brazil (n = 1461), accordingly. The frequency of research outcomes in various nations differs among the 25 leading countries from 0.625 to 0.059. The top leading nations with Multiple Country Publications (MCP), include China (n = 25), UK (n = 21), USA (n = 20), Brazil (n = 20), and Spain (n = 15), respectively. The nations ranked in top positions for number of single country publications (SCP) of research include China (n = 120), USA (n = 96), South Korea (n = 43), Brazil (n = 39), Spain (n = 26), Japan (n = 23), and UK (n = 20), respectively.

Table 1: Research on cultured meat from 1952 – 2023 in summary

Description	Results
Main Information About Data	
Timespan	1952:2023
Sources (Journals, Books, etc)	554
Documents	1108
Annual Growth Rate %	7.29
Document Average Age	13.4
Average citations per doc	28.74
Document Contents	
Keywords Plus (ID)	7108
Author's Keywords (DE)	2730
Authors	
Authors	3836
Authors of single-authored docs	94
Authors Collaboration	
Single-authored docs	109
Co-Authors per Doc	4.64
International co-authorships %	20.22
Document Types	
Article	1108

Table 2: Top 25 leading nations on cultured meat research based on article and citation numbers from 1952 – 2023

S/N	Country	Articles	SCP	MCP	Freq	MCP_Ratio	Country	TC	AAC
1	China	145	120	25	0.131	0.172	UK	3634	88.60
2	USA	116	96	20	0.105	0.172	USA	3232	27.90
3	Brazil	59	39	20	0.053	0.339	China	1857	12.80
4	Korea	45	43	2	0.041	0.044	Brazil	1461	24.80
5	Spain	41	26	15	0.037	0.366	Spain	1402	34.20
6	UK	41	20	21	0.037	0.512	Ireland	1025	256.20
7	Japan	26	23	3	0.023	0.115	Netherlands	1025	64.10
8	Germany	22	13	9	0.02	0.409	France	680	56.70
9	Australia	18	14	4	0.016	0.222	Switzerland	673	84.10
10	Turkey	17	16	1	0.015	0.059	Germany	597	27.10
11	Netherlands	16	13	3	0.014	0.188	KOREA	506	11.20
12	Italy	15	9	6	0.014	0.4	Japan	484	18.60
13	Canada	14	10	4	0.013	0.286	Turkey	408	24.00
14	India	14	13	1	0.013	0.071	Sweden	402	57.40
15	France	12	8	4	0.011	0.333	Israel	394	43.80
16	Thailand	11	7	4	0.01	0.364	New Zealand	377	53.90
17	Iran	9	9	0	0.008	0	India	338	24.10
18	Israel	9	8	1	0.008	0.111	Belgium	284	47.30
19	Mexico	9	4	5	0.008	0.556	Denmark	258	32.20
20	Singapore	9	7	2	0.008	0.222	Australia	248	13.80
21	Denmark	8	3	5	0.007	0.625	Canada	244	17.40
22	Poland	8	7	1	0.007	0.125	Italy	224	14.90
23	Switzerland	8	6	2	0.007	0.25	Norway	204	40.80
24	New Zealand	7	5	2	0.006	0.286	Mexico	188	20.90
25	Sweden	7	6	1	0.006	0.143	Portugal	141	28.20

SCP Single Country Publications; MCP Multiple Country Publications; TC Total Citations; AAC Average Article Citations

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Table 3: The 30 most relevant words used by authors in cultured meat research from 1952-2023

S/N	Keywords (DE)	Occurrences	Keywords Plus (ID)	Occurrences
1	Cultured Meat	105	Article	421
2	Cultivated Meat	57	Animals	364
3	Chicken	50	Animal	357
4	*in vitro* Meat	41	Nonhuman	340
5	Meat	31	Meat	326
6	Artificial Meat	28	Chicken	281
7	Healthier Meat Products	28	Animal Cell	230
8	Cell-Based Meat	24	Chick Embryo	216
9	Cellular Agriculture	23	Controlled Study	207
10	Lab-Grown Meat	23	Cells	196
11	Clean Meat	21	Cell Culture	192
12	Fatty Acids	18	Priority Journal	183
13	Sustainability	17	Cultured	164
14	Lipid Oxidation	16	Male	156
15	Meat Quality	15	Human	155
16	Plant-Based Meat	14	Female	154
17	Animal Welfare	13	Chickens	149
18	Consumer Acceptance	13	Meats	149
19	Alternative Protein	12	Gallus Gallus	130
20	Food	12	Animalia	113
21	Tissue Engineering	12	Humans	107
22	In-Vitro Meat	11	Metabolism	104
23	Alternative Proteins	10	*in vitro* Study	102
24	Biotechnology	10	Embryo	100
25	Cell-Cultured Meat	10	Support	96
26	Cell Culture	10	Meat Products	95
27	Fatty Acid Profile	10	Cell Proliferation	94
28	Healthy Meat	10	Animal Experiment	90
29	Healthy Meat Products	10	Muscle	89
30	Beef	9	Gene expression	84

The top leading 30 keywords (author's keywords) by scientists in this discipline of research include Cultured meat (n = 105), next was Cultivated meat (n = 57), followed by Chicken (n = 50), *in vitro* meat and Meat (n = 31) among others (Table 3). The 25 top ranked journal sources with the highest published articles on cultured meat is presented in Table 4. These journal sources include Meat Science (n = 40; h_index = 25), Foods (n = 38; h_index = 17), Proceedings Of The National Academy of Sciences of the United States of America (n = 16; h_index = 15) and Journal of Biological Chemistry (n = 14; h_idex = 13), respectively. The 25 top ranked institutions are shown in Table 5. These institutions includes; University of California (n = 55), Jiangnan University (n = 30), Centro Tecnológico de Carne de Galicia (n = 27), Nanjing Agricultural University (n = 22), Northeast Agricultural University (n = 18), and Tufts University (n = 18), respectively.

Table 6 presented the 25 top leading globally cited publications on cultured meat research which is based on the total number of citations attracted by each paper from 1952 to 2023. The article authored by Wood JD (Wood *et al.*, 2004) as the first author (Meat Science Journal) was ranked first with an aggregate of 1884 citations. The second placed article was written by Henchion M (Henchion *et al.*, 2017) being the first author (in Foods Journal) with a sum of 802 citations. The third (n = 531), fourth (n = 393), fifth (n = 388) and sixth (n = 351) articles were written by Geiger B (Geiger, 1979), Chang HW (Chang *et al.*, 1997), Geiger B (Geiger *et al.*, 1980) and Smetana S (Smetana *et al.*, 2015) being the first authors of these afore-mentioned papers, respectively. It is worthy of note, that the author Geiger B had two (2) papers featuring in the top leading cited papers in cultured meat. Table 7 further presented the 25 top global leading authors in the field of cultured meat based on the number of publications and h_index in the discipline. These authors include Lorenzo JM (n = 29; h_index = 15), Campagnol PCB (n = 17; h_index = 12), Cichoski AJ (n = 12; h_index = 10), Domínguez R (n = 14; h_index = 10), Pateiro M (n = 13; h_index = 10), and Heck RT (n = 8; h_index = 8), accordingly.

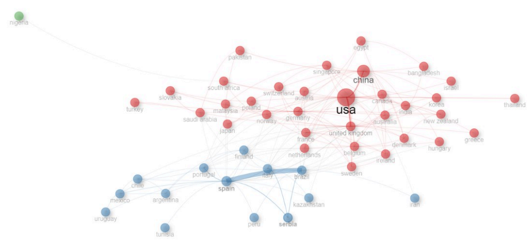

Fig. 3: Mappings of networking among countries involved in research on cultured meat from 1952-2023

Fig. 4: Networking strength of author keywords of global research on cultured meat from 1952 – 2023

Figure 3, showed the collaboration map of nations network involved in research on cultured meat globally co-operation. From the diagram, a node represents individual country while the radius of each node to the other depicts article number by each nation. The strokes showed the direction of networking among the different countries while the thickness of each stroke indicates the degree of networking. The different colours represented the collaboration alignments (common interest) of the different countries in the research discipline. Figure 4, showed the co-occurrence networking of the leading keywords on culture meat as used among researchers within the research discipline. Each circle with different

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colours indicates a group of terms (on cultured meat research) and the lines represents the links in relation to the keywords on the subject of discourse. The closeness of each of the different keywords indicate how relatedly close the research topics are during the study span between 1952 – 2023.

Table 4: The 25 most relevant journal source in cultured meat research from 1952-2023 based on h_index, citation and article numbers

S/N	Element	h_index	g_index	m_index	TC	NP	PY_start
1	Meat Science	25	40	1.087	4109	40	2002
2	Foods	17	38	2.125	1682	38	2017
3	Proceedings of the National Academy of Sciences of the United States of America	15	16	0.319	1388	16	1978
4	Journal of Biological Chemistry	13	14	0.26	614	14	1975
5	Journal of Virology	12	13	0.235	612	13	1974
6	Biomaterials	11	11	2.75	369	11	2021
7	Appetite	10	12	0.833	862	12	2013
8	Journal of Food Processing and Preservation	8	15	0.8	246	19	2015
9	LWT	8	9	0.571	284	9	2011
10	Developmental Biology	7	7	0.2	337	7	1990
11	Frontiers in Sustainable Food Systems	7	13	1.167	645	13	2019
12	Journal of Agricultural and Environmental Ethics	7	8	0.412	480	8	2008
13	Journal of Cell Biology	7	7	0.171	830	7	1984
14	Journal of Cellular Biochemistry	7	7	0.212	123	7	1992
15	Journal of Food Science	7	9	0.156	226	9	1980
16	Journal of the Science of Food and Agriculture	7	7	0.156	412	7	1980
17	Poultry Science	7	11	0.127	183	11	1970
18	Biochemical and Biophysical Research Communications	6	8	0.14	297	8	1982
19	Experimental Cell Research	6	9	0.086	89	10	1955
20	Food Chemistry	6	7	0.214	226	7	1997
21	International Journal of Food Science & Technology	6	6	0.3	159	6	2005
22	Journal of Cellular Physiology	6	7	0.113	407	7	1972
23	PLOS ONE	6	10	0.462	183	10	2012
24	Animals	5	7	0.417	145	7	2013
25	Food Policy	5	5	1	293	5	2020

TC Total Citation; NP Number of Publications; PY_Start Publication Start Year

Figure 5 showed the authors' keywords through the thematic map representation. This result showed four (4) distinct quadrants in line with the authors' keywords. These quadrants include the emerging class, niche class, basic class and motor class. The motor class had keywords very closely related and shared with the basic class such as healthier meat products, fatty acids and lipid oxidation. This aspect of research focuses on cultured meat as relates to consumers' health. The emerging class also closely linked with the basic class. The keywords shared by both of these class include cultured meat, cultivated meat and *in vitro* meat. This aspect of research focuses on cultured meat as relates to the different nomenclatures used to portray cultured meat research. Finally, the niche class had keywords such as chicken, proliferation and hepatocytes which relates to production and products of cultured meat research. Likewise, Figure 6 presented the conceptual frame work of the research discipline that explained the k – means clustering with only one cluster depicting the concepts of cultured meat research that is done globally. The result in Figure 7 described the contents of the author keywords as well as pointing research scholars to a good representation of cultured meat research. This result tells about the topic trends and growing focus of research for future directions on this subject of discourse.

Table 5: The 25 leading research organizations involved in cultured meat research from 1952-2023

S/N	Affiliation	Nations	Articles
1	University of California	USA	55
2	Jiangnan University	China	30
3	Centro Tecnológico de Carne de Galicia	Spain	27
4	Nanjing Agricultural University	China	22
5	Northeast Agricultural University	China	18
6	Tufts University	USA	18
7	Universidade Federal de Santa Maria	Brazil	17
8	Chonnam National University	South Korea	16
9	Seoul National University	South Korea	16
10	Zhejiang University	China	14
11	National University of Singapore	Singapore	12
12	Instituto Politécnico de Bragança	Portugal	11
13	Iowa State University	USA	11
14	Kangwon National University	South Korea	11
15	Chiba University	Japan	10
16	University of Bath	England (UK)	10
17	Universal College of Parañaque	Brazil	9
18	Universidad Federal de Río Grande del Sur	Brazil	9
19	Universidad Técnica Federico Santa María	Chile	9
20	University of Helsinki	Finland	9
21	Aarhus University	Denmark	8
22	Chiang Mai University	Thailand	8
23	Ege Üniversitesi	Turkey	8
24	Maastricht University	Netherlands	8
25	National Taiwan University	Taiwan	8

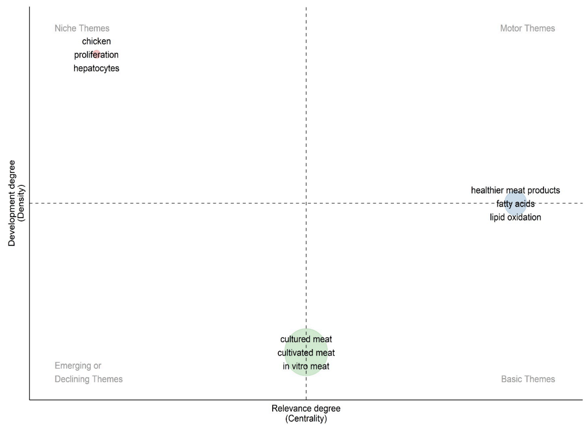

Fig. 5: Thematic map (author-keywords) on cultured meat research from 1952 – 2023

Table 6: Top 25 most cited publications on cultured meat research from 1952-2023

S/N	Paper	DOI	Total Citations	TC per Year	Normalized TC
1	Wood JD, 2004, Meat Sci	10.1016/S0309-1740(03)00022-6	1884	89.71	5.73
2	Henchion M, 2017, Foods	10.3390/foods6070053	802	100.25	15.92
3	Geiger B, 1979, Cell	10.1016/0092-8674(79)90368-4	531	11.54	2.42
4	Chang HW, 1997, Science	10.1126/science.276.5320.1848	393	14.04	8.05
5	Geiger B, 1980, Proc Natl Acad Sci USA	10.1073/pnas.77.7.4127	388	8.62	4.29
6	Smetana S, 2015, Int J Life Cycle Assess	10.1007/s11367-015-0931-6	351	35.10	6.15
7	Fontaine B, 1986, Neurosci Lett	10.1016/0304-3940(86)90257-0	283	7.26	2.77
8	Bryant C, 2019, Front Sustain Food Syst	10.3389/fsufs.2019.00011	272	45.33	6.15
9	Bernués A, 2003, Food Qual Preference	10.1016/S0950-3293(02)00085-X	258	11.73	6.00
10	Bax ML, 2012, J Agric Food Chem	10.1021/jf205280y	242	18.62	6.99
11	Van Loo EJ, 2020, Food Policy	10.1016/j.foodpol.2020.101931	235	47.00	7.83
12	Ajubi NE, 1996, Biochem Biophys Res Commun	10.1006/bbrc.1996.1131	233	8.03	6.38
13	Mattick CS, 2015, Environ Sci Technol	10.1021/acs.est.5b01614	231	23.10	4.05
14	Post MJ, 2014, J Sci Food Agric	10.1002/jsfa.6474	230	20.91	6.07
15	Lynch J, 2019, Front Sustain Food Syst	10.3389/fsufs.2019.00005	217	36.17	4.91
16	Fontaine B, 1987, J Cell Biol	10.1083/jcb.105.3.1337	216	5.68	5.62
17	Kennedy SW, 1993, Anal Biochem	10.1006/abio.1993.1239	216	6.75	3.72
18	Röös E, 2017, Global Environ Change	10.1016/j.gloenvcha.2017.09.001	215	26.88	4.27
19	Miyauchi A, 1990, J Cell Biol	NA	213	6.09	5.40
20	Ben-Arye T, 2020, Nat Food	10.1038/s43016-020-0046-5	202	40.40	6.73
21	Siegrist M, 2018, Meat Sci	10.1016/j.meatsci.2018.02.007	194	27.71	7.04
22	Liang BT, 1998, Proc Natl Acad Sci USA	10.1073/pnas.95.12.6995	183	6.78	4.77
23	Siegrist M, 2017, Appetite	10.1016/j.appet.2017.03.019	178	22.25	3.53
24	Hopkins PD, 2008, J Agric Environ Ethics	10.1007/s10806-008-9110-0	166	9.76	5.75
25	Oishi I, 2016, Sci Rep	10.1038/srep23980	159	17.67	5.02

Table 7: 25 top leading authors doing research in cultured meat from 1952-2023

S/N	Element	h_index	g_index	m_index	TC	NP	PY_start
1	Lorenzo JM	15	29	1.875	1179	29	2017
2	Campagnol PCB	12	17	0.667	816	17	2007
3	Cichoski AJ	10	12	1.25	701	12	2017
4	Domínguez R	10	14	2	398	14	2020
5	Pateiro M	10	13	2	476	13	2020
6	Heck RT	8	8	1	521	8	2017
7	Hocquette JF	8	9	0.667	449	9	2013
8	Wagner R	8	9	1	480	9	2017
9	Hightower LE	7	7	0.163	388	7	1982
10	Kaplan DL	7	10	1.167	327	10	2019
11	Li S	7	12	0.269	160	15	1999
12	Liu J	7	7	0.368	260	7	2006
13	Post MJ	7	9	0.467	605	9	2010
14	Ruiz-Capillas C	7	8	0.389	303	8	2007
15	Wang X	7	13	0.7	173	13	2015
16	Wang Y	7	10	0.538	114	15	2012
17	Zhang Y	7	11	0.538	136	12	2012
18	Chen J	6	10	1	120	10	2019
19	De Menezes CR	6	6	0.75	417	6	2017
20	Du G	6	7	1	110	7	2019
21	Li H	6	8	0.462	78	11	2012
22	Li X	6	12	0.231	181	12	1999
23	Li Y	6	7	1	60	14	2019
24	Stephens N	6	6	0.5	258	6	2013
25	Trindade MA	6	7	0.857	194	7	2018

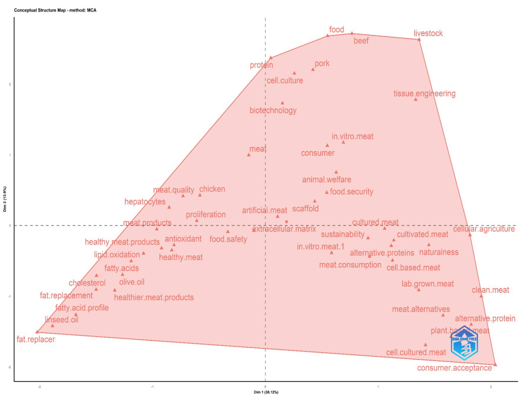

Fig. 6: Conceptual frames as relates to cultured meat research from 1952 to 2023. The retrieved publications exhibited K-means clustering with one (1) cluster showing models of various niche of the research areas

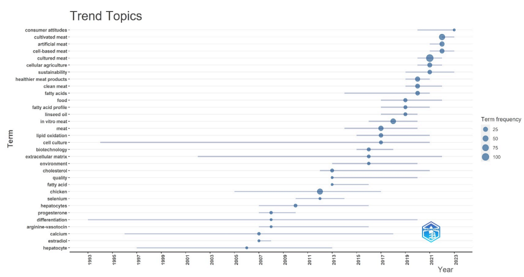

Fig. 7: Trending topics (author keywords) on cultured meat research with high frequency terminologies over 25 – 100

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Discussion

This study utilized bibliometric approach to assess findings from several research publications on cultured meat between 1952 and 2023 based on data extracted from Scopus. The number of articles on cultured meat from the year 1952 initially exhibited a fluctuating tendencies with few of the years not having a single research publication while some years had small number of publications. There was however, a noticeable rise in research publications on cultured meat from 1982 (n = 10) to 2023 (n = 184). The rise in articles indicates a growing interest for research work on cultured meat by scientists, institutions as well as other stakeholders interested on the subject matter. This finding corresponded with the reports from previous studies that also recorded increase in research work on cultured meat as the years increased in recent times (Fernandes *et al.*, 2019; Song *et al.*, 2024; Xie *et al.*, 2024). The production of meat through cellular agriculture has been accepted as an approach to reduce future negative impacts of the global human population growth for the coming decades (Fernandes *et al.*, 2019), hence the increase in interest by researchers. Among the arrays of alternative options available for producing animal protein food source for human consumption, cultured meat stands out as a protein source to fill the gap of meeting sustainable production of animal protein food source in the future. Several scientists have, thus been advancing efforts to develop this scientific research discipline today (Fernandes *et al.*, 2019; Nyika *et al.*, 2021).

With regards to number of publications, more research were done in advance and economically stable nations such as China, USA, Korea, Spain, UK, Japan, Germany and Australia among others. In agreement with this findings, the afore-mentioned nations have been reported to be top leading nations in research on cultured meat (Nyika *et al.*, 2021; Song *et al.*, 2024; Xie *et al.*, 2024). Several reasons have been highlighted for the increase in research work in advanced nations as compared to developing nations. One of such reasons may be linked to the fact that researchers, government institutions and other stakeholders understands the importance of meeting the nutritional and food needs of their citizens, as such, they are creating innovative systems for increasing production of animal protein such as cultured meat. In addition, these nations were largely developed where sensitization of sustainable food production as well as ecological conservation is high at a time of reduced limited resources and climate change (Wang *et al.*, 2018; Izuchukwu *et al.*, 2020). Meanwhile, similar research of this nature in developing nations may be limited as a result of low human as well as limited technical know-how and financial constraints (Zhong *et al.*, 2016) to carry out research on cultured meat (Nyika *et al.*, 2021).

The quest by researchers, stakeholders and government institutions in several economically prosperous nations to explore better effective ways to increase meat availability and sustainability for it populace for the purpose of ameliorating the effective of population growth on demands for meat in the future (as predicted by WHO) has increased. These again are part of the reasons why they are consciously involved in lots of research work in this research discipline (Aiking, 2014; Fernandes *et al.*, 2019; Song *et al.*, 2024). Likewise, several research bodies from advance nations are hugely subsidized by global institutions to do research that aligns with resolving human problems (Peng *et al.*, 2015).

The present investigation also keenly noticed that there was no single African nation out of the 25 top leading regions that are doing active research on cultured meat production (Table 2). This observation is a wake up challenge to nations in Africa and other developing regions that recorded either no contributions (out of the top 25 nations) or few number of research work to step up their game in this discipline. Developing nations can tap into this innovative aspect of research if they hope to tackle the problem of high demand of meat by the surging population of their citizens in the future. More importantly, the fact that this field (production of cultured meat) of research is believed by some quarters to have lower contribution to greenhouse gases (GHG), limited usage of land space and water as compared to extensive system of livestock farming (Aiking, 2014; Chriki and Hocquette, 2020) is another reason why it should be adopted by more countries of the world.

Conversely, the fairly low number of research on cultured meat as observed in the present study (developing nations) may be due to the fact that researches carried in these nations are self-funded. Developing nations involved in self-funding usually do less number of research due to lack of well-equipped facilities to do standard research (Orimoloye and Ololade, 2021). Another conceivable reason for low numbers of research could further be that researchers/ scientists from these countries maybe publishing their research results in a non-indexed intellectually recognized sources such as WOS, Scopus and PubMed etc.

The 25 top leading countries having Multiple Collaboration Publications (MCP) on outputs in cultured meat shows that they mostly network with colleagues that are researchers from economically stable and advance countries including China, USA, Brazil, Spain and UK (Table 2). The present observation is inline with findings of other bibliometric studies who also recounted that research networking are often among nations with economical stable economies and advanced in science (Smith *et al.*, 2021). Research partnerships between developed and developing nations is however noticeably scanty as similarly reported from previous studies (Ekundayo and Okoh, 2018; Orimoloye and Ololade, 2021). Meanwhile, in another study by Song *et al.*

(2024), it was reported that an American researcher had a collaboration with a South African institution, who did a study on consumer perceptions on cultured and plant-based meat in South Africa. This kind of study should be encouraged not only in South Africa but, in several other developing nations in order to boost more meat production in the region and beyond. Although, research work on cultured meat is relatively a new area of research in South Africa especially as relates to several cultural beliefs among several tribes from that area, some researchers are already exploring this field of research as a possible option for increasing meat production (Szejda *et al.*, 2021; Falowo *et al.*, 2022; Tsvakirai *et al.*, 2023a-b)

Intellectual exchange of ideas and expertise in a discipline among researchers from different countries is very important because it creates an avenue for effective executions of innovative research that will have a possible global significance in promoting impact in that research discipline (Lloyd *et al.*, 2023). Some studies have reported that lack of global networking among countries (whether among developing ones or among developed and developing nations) in research may affect research citations because intellectual exchange of inputs, funds as well as expertise from different customs and environments helps to grow the number of citations of a research work (Ekundayo and Okoh, 2018; Smith *et al.*, 2021).

Considering the terminology "keywords" in bibliometric studies, they are used in manuscripts to capture the themes of vital issues of a research discipline and to give the general scope and directions of the study to academics and readers (Chen, 2021). Furthermore, keywords are used to point cutting hedge illustrations of a research paper (Synnestvedt *et al.*, 2005). It is often required by academic journals during manuscript submission prior to the review submission. This is an indication of their importance during manuscript review procedures (Okaiyeto and Oguntibeju, 2021). This study employed use of both the singular (author keywords) as well as the plural (keywords plus) search for the subject matter keywords to describe the frequently occurring words as keywords on cultured meat as relates to food security and sustainability. This approach of keyword search has earlier been adopted by fellow researchers to comprehend the coverage of research trends that are emerging as well as current within a prescribe discipline (Cañas-Guerrero *et al.*, 2013). Using author keywords is highly recommended in bibliometric assessments because they are a collection of terms that mirrors the exact story of a research of a particular discipline; whereas keyword-plus provides a range of references for titles of different manuscripts (Zhang *et al.*, 2016).

The routinely used keywords in a particular research discipline demonstrates the most discussed topics over a period of time by authors in that field. Between the year 1952 and 2023, an aggregate of 2730 author keywords and 7108 keyword-plus were retrieved from Scopus on cultured meat as related to food security (Table 1). These frequently appearing author keywords and keyword plus for this subject matter includes Cultured Meat, Cultivated Meat, Chicken, Meat, *in vitro* Meat, Artificial Meat, Healthier Meat Products, Cell-Based Meat, Cellular Agriculture, Lab-Grown Meat, Clean Meat, Fatty Acids, Sustainability, Lipid Oxidation, Meat Quality, Plant-Based Meat, Animal Welfare, Consumer Acceptance, Alternative Protein, Food among others are relevant to the research discipline related to culture meat as relates to food security (Table 3). In agreement with the present study, other related studies also reported similar author keywords for cultured meat research (Fernandes *et al.*, 2019; Nyika *et al.*, 2021; Song *et al.*, 2024). This buttresses the significance of the afore-mentioned keywords in explaining the scope of the present topic of discourse and its use in the discipline of cultured meat research.

From the result of the 25 most rated journal sources in Table 4, it showed that they are relevant journal outlets devoted to publishing research findings related to cultured meat. These top ranked journals with their h_index score from Table 4 include the following; Meat Science (n = 40; h_index = 25), Foods (n = 38; h_index = 17), Proceedings of The National Academy of Sciences of The United States of America (n = 16; h_index = 15), Journal Of Biological Chemistry (n = 14; h_index = 13), Biomaterials (n = 11; h_index = 11), and Appetite (n = 12; h_index = 10). The calibre of research outputs produced by the afore-mentioned journals and their h_index rankings shows that they have the capacity to publish research investigations on cultured meat as relates to food security. In line with the present study, some of these journals were listed as top ranked journals for research studies done on cultured meat (Nyika *et al.*, 2021; Song *et al.*, 2024). The Meat Science journal that topped the list of relevant journals is a well-known journal with Elsevier as its publisher. This journal is committed to publishing research work on meat production, preparation, preservation and are also devoted to publishing research on artificial meat such as cultures of muscle cells, hence justifying its ranking in the top placed position.

In Table 5, the top leading research institutions that produced more research findings on cultured meat was presented with the nations from China, USA and Brazil having more institutions doing research in this discipline. Most research institutions ranked in this categories had over 7 research publications with University of California (USA) and Jiangnan University (China) having the highest number of articles (n = 55; n = 30), respectively. In line with this observation, several of the listed institutions (Table 5) have also been previously reported to be active in doing research on cultured meat (Song *et al.*, 2024). Meanwhile, just like in other bibliometric studies, it has been observed that several institutions that are based in the USA and China make more scholarly contributions to academic knowledge when compared to other regions of the world (Ekundayo and Okoh, 2020; Orimoloye and Ololade, 2021; Okaiyeto and Oguntibeju, 2021; Idamokoro and Hosu, 2022). These two nations and a couple of others (Table 5) are known to invest large funds in research thereby making them the leading nations in scientific inventions and innovations (Ekundayo and Okoh, 2020; Idamokoro, 2023).

Considering the citation indexes of articles and their scholarly impact globally, the common yardstick used to grade the global influence of articles is through the number of times that they have attracted citations over the years couple with the number of times that they have been downloaded by other colleagues in the field. Furthermore, the number of article citations of a particular manuscript is also linked to the academic strength of other citing research papers. When a research paper is cited by a high impact factor journal, it will always attract the attention of other scholars in the research field which in turn impact the global rating of that research paper globally. The scholarly performance of a manuscript within a research discipline is commonly based on how often it attracts citation from other peers in the field (Tahim *et al.*, 2016). Equally, the performance of a well-written academic paper increases in its significance with increase in citation.

The top 25 most ranked articles with regards to Total Citations (TCs) and total number of citations per year (TC/Year) in research on cultured meat as relates to food security from 1952 – 2023 were presented in Table 6. Several of the articles were written by authors including; Wood JD, Henchion M, Geiger B, Chang HW, Smetana S, and Fontaine B were among researchers who had articles on cultured meat with more numbers of citations. Howbeit, the names of Geiger B, Fontaine B and Siegrist M stood out clearly among the authors with highly ranked articles because each of them had two (2) articles each on the subject matter of discourse. The exploits of research by these authors (Geiger B, Fontaine B and Siegrist M) on cultured cells cannot be over-emphasized as the global impact of their research findings speaks for itself. Interestingly, Geiber, B is a cell biologist from the University of California, USA, an institution that is ranked (Table 5) in the first position for doing research on cultured meat. In accordance with the present findings, previous studies also listed these authors as researchers with research work in cultured meat (Fernandes *et al.*, 2019; Nyika *et al.*, 2021; Song *et al.*, 2024). Meanwhile, there is a possibility that some of the highly ranked articles in Table 6 may attract negative criticisms because of result inconsistencies with other results from other authors. This kind of criticism is usually common among scholars and research findings (Cheek *et al.*, 2006). From the work of one of the top cited research publication (Table 6), the authors discovered that the acceptance of cultured meat by consumers is greatly influenced by the way the nutritional benefits are explained to people than how the meat is being processed (Siegrist *et al.*, 2018). Thus, it is very essential and germane to elucidate cultured meat in a nontechnical manner that stressed on the final product (health-wise), and not on how the product is made to increase acceptance of the novel animal protein by people. In another highly ranked article (Table 6), the author explained the practicality with proof of the concept that edible meat (beef) can be manufactured in the laboratories from stem cells of animals and this innovative technology is capable of re-writing the narratives of the possible animal protein alternatives to replace the worrisome future of livestock meat production menace in the bid to feed the ever growing human population in the near future (Post, 2014).

In Table 7, the present study outlined the leading scientists on research work done on cultured meat. The leading authors which include Lorenzo JM, Campagnol PCB, Cichoski AJ, Domínguez R, Pateiro M, Heck RT, and Hocquette JF (n = 29; n = 17; n = 12; n = 14; n = 13; n = 8; n = 9) are placed in their order of contributions to the current discipline of discourse, respectively. From the academic profile of these authors, they have h-index of 15, 15, 10, 10, 10, 8, and 8 (with citation numbers of 1179, 816, 701, 398, 476, 521 and 449), respectively.

The h-index is often used to calculate how significant authors and articles are ranked globally (Huang *et al.*, 2019). Furthermore, the h_index is used to describe how productive and active scientists within a research field is involved in research work and this is usually achieved based on the number of articles the authors have produced and the citation numbers of their articles over the years (Hirsch, 2005). The h_index is mathematically calculated using the h – algorithm (article numbers) on the minimum number of h times the article was cited by other authors in the research domain (Hirsch, 2005). Importantly, it is very essential to know that the h_index criteria for evaluating any author's scholarly impact on the global stage is an essential tool in bibliometric studies because it has a widely accepted level of accuracy to reproduces the needed impact of a given author and their contributions to scientific knowledge over the years (Guilak and Jacobs, 2011). In agreement with the current result, previous studies also listed several of these authors (Table 7) as researchers that are actively involved in doing research on cultured meat (Fernandes *et al.*, 2019; Nyika *et al.*, 2021; Song *et al.*, 2024).

Another important aspect of bibliometric evaluation for a research field is that of networking and partnership among scientists, nations and research organization because it forms a standard required for promoting academic discoveries in any research area. In addition, research networking helps to foster partnership among scholars, nations, or research agencies with the same goal and interest in a related research field. Networking also allows for inter-disciplinary exchange of expertise from different perceptions among intellectuals having similar interest in order to realize loftier research benefits (Wu *et al.*, 2019). Networking in research also enhance the quality of research findings. Other benefits of research networking includes ground-breaking innovations, local and international exchange of intellectual human potentials, publishing of results in high impact journals, and funds accessibility (Bozeman *et al.*, 2013).

From the current study, the result of nation's networking is presented in Figure (3) with different colours depicting its different clusters with respect to their networking with other nations of the world. The different nodes also depicts each nation while the lines joining the different nations together have different degree of thickness. The connection of this strokes indicates the strength in ties among these different nations. China had the most network connections with other nations due to the thickness and numbers of strokes and the size of its node. The central placement of China is another indication of its rankings as the leading country with more networking with other nations of the world. On the contrary the current result is in contrast with findings of other bibliometric studies who often report that the USA has more networking with other nations in doing research (Baier-Fuentes *et al.*, 2020; Ekundayo and Okoh, 2020; Xie *et al.*, 2024).

The keyword co-occurrence assessment for this study was also carried out. Keyword assessment helps to define the different areas of research that is inline with the present topic of discourse. Considering the result in Figure 4 indicates that the main author keywords in this research discipline using a threshold of co-occurrences as well as the fifty most-frequent coincidences of vital keywords for cultured meat research. This method of bibliometric analysis gives a cue of the most recent concepts inline with the research subject matter. The main keywords for this study are "cultured meat", "cultivated meat", *in vitro* meat", "chicken", "sustainability" and "cellular agriculture". Interesting to note that other associated concepts that appeared to be derivatives to the concept of cultured meat are those related to healthy meat including "meat quality", "fatty acids", and "cholesterol". It is also of interest to state that other concepts have been associated to cultured meat research in recent years. This could be observed from the other colours in Figure 4 (such as healthy meat, meat products and lipid oxidations). All these keywords points to the varied conceptual frameworks adopted to describe the intersection of the present topic of discourse (cultured meat as relates to food security). In accordance to our findings other related studies also found similar results (Nyika *et al.*, 2021; Song *et al.*, 2024).

With respect to Figure 5, it showed the authors' keywords using another kind of evaluation analysis named the thematic evaluation map to explain the significance of the author's keywords used during the study span (1952 to 2023). This kind of bibliometric assessment has previously been employed to present the progression of keywords (Cobo *et al.*, 2011; Altarturi *et al.*, 2023). This current study presents the four (4) key schemes that model the authors' keywords classification namely;

1. The motor theme (top-right quadrant) which explains the high centrality and the concentration keywords of cultured meat research. From this map, the author keywords such as healthier meat products, fatty acids and lipid oxidation.
2. The niche theme (top-left quadrant) which explains themes such as chicken, proliferation and hepatocytes. This theme is still not well developed as it is still evolving, but it has links with the other main keywords on cultured meat research.
3. The basic theme (bottom-right quadrant) and the declining theme (the bottom-left quadrant) which both occupies the centrality of the subject matter had keywords linked to cultured meat, cultivated meat and *in vitro* meat.

The afore-mentioned grouped themes projects the degree of relevance (centrality) of the different keywords in the thematic chart as linked to the main theme of the subject matter which is cultured meat and food security.

In recent years there have been a growing interest on cultured meat research (also known as cultivated meat, *in vitro* meat, clean meat, lab meat, cell meat among other names) in several nations of the world, predominantly in developed nations (Shapiro, 2018; Pakseresht *et al.*, 2022). Although, there are still issues and concerns with regards to cultures, healthiness of the meat, environmental implications of production, public health concerns of consumers among others (Alexander *et al.*, 2017; Pakseresht *et al.*, 2022; Song *et al.*, 2024). Nonetheless, research findings from many quarters have supported the viability and sustainability of cultured meat for the purpose of meeting the growing challenge of global population with respect to food availability and security (Moritz *et al.*, 2015; Hocquette, 2016; Stephens *et al.*, 2018a; Wang *et al.*, 2023; Xie *et al.*, 2024). However, some obstacles are still being faced in the art of production and sustainability of cultured meat. With regard to technical barriers, there is a need for the development of new cell lines with differentiation potential (Specht *et al.*, 2018), the identification of alternatives for the use of completely synthetic culture media, similar to those developed for medical purposes (Post, 2012). Beyond that, aspects that relates to the economic viability of the production process are still raised, given that the cost of certain elements, such as scaffolding, for example, are still high (Datar and Betti, 2010), making the product extremely expensive in the short term (Bhat and Bhat, 2011).

Study Limitations

The for the present bibliometric study was entirely from the Scopus data archive, thus it may not have included all published articles on cultured meat research. Meanwhile, as previously alluded to in the methodology section of this manuscript, Scopus data base is a broadly accepted knowledge base that is widely consulted as a data source among academics, researchers, scientists as well as scholars all over the world. It is recommended that other possible alternative datasets such as PubMed, Google Scholar as well as Web of Science (WOS) among others can be utilized in the future for this kind of study. Nonetheless, the current study still offers immense insights on the global viewpoints and trends as well as future directions in the field of cultured meat as relates to its importance in augmenting food and alternative protein production for the ever growing human population.

Conclusion

Research result on the bibliometric assessment on cultured meat for this study indicates that it is gaining global attention as observed from the annual scientific production (ASP) from 1952 to 2023. This growth in research work on cultured meat is very encouraging due to the significance of the discussed topic especially as it relates to tackling the situation of finding alternative animal protein food source that will help meet the ever growing human meat demands. Economically buoyant and scientifically advance industrial countries showed greater involvements in research investigations on the present research subject matter as compared to other nations (especially under-developed and developing nations). Other countries (researchers, government agents and private institutions) of the world are encouraged to network with active countries in this research discipline so that together they can further increase research on finding more innovative solutions to increasing meat production through cell-culture of edible livestock.

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