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A Bibliometric Review and the Direction of Future Vegan-Related Research: A Qualitative Approach

Hong Chuan Loh, BPharm , Jia Ni Kwan, BMedSci, MD,
Yi Fang Lim, MD, Fan Kee Hoo, MD, MRCP,
Irene Looi, MBBS, FRCP

Abstract

Veganism, a lifestyle that encourages healthy and sustainable living, is gaining more attention. The rising demand for sustainable ways of living has stimulated research initiatives globally. We sought to comprehend the topics of interest to researchers and took a qualitative approach in examining vegan-related research trends worldwide. This article aims to provide a synthesis of underlying research themes and identify the direction of future vegan-related research. We selected relevant articles published between 1960 and 2020 from the Scopus database and performed a bibliographic coupling analysis with the open-source R programming software-based Bibliometrix package followed by a content analysis. We identified four main clusters and the associated subclusters for each of them: a) consumerism (cultural, social, personal, and psychological factors), b) medical and health sciences (nutrition, biomarkers, anthropometry, fat and/or cholesterol, blood glucose, gut health, blood pressure, general health, ageing and/or quality of life, physical or exercise performance, mortality or longevity, bone health, and genetics), c) food science and technology (vegan food products or by-products, vegan vitamins or supplements, and vegan food content or toxic elements), and d) environmental impacts (greenhouse gas emissions, land and water use). Our study provides a wide-ranging overview of research domains and introduces readers to key studies, concepts, and methods. These are essential to help researchers conduct more studies for effective policy prescriptions.

Keywords: bibliometric, vegan, qualitative, research, trend

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Hong Chuan Loh[a], Jia Ni Kwan[a], Yi Fang Lim[a], Fan Kee Hoo[b], & Irene Looi[a,c]

Affiliations
[a]Clinical Research Centre, Hospital Seberang Jaya, Ministry of Health Malaysia, 13700 Seberang Jaya, Penang, Malaysia

[b]Neurology Unit, Department of Medicine, Faculty of Medicine and Health Sciences, Universiti Putra Malaysia, 43400 Serdang, Selangor, Malaysia

[c]Medical Department, Hospital Seberang Jaya, Ministry of Health Malaysia, 13700 Seberang Jaya, Penang, Malaysia

Corresponding author
Hong Chuan Loh
Email: lohhongchuan@gmail.com

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Introduction

The growing popularity of veganism is evident in various industries such as food, fashion, textiles, household, and cosmetics. The Global Meat Substitute Market Analysis Survey 2021 reported that in the Asia Pacific region, soy-based products rich in vitamins, amino acids, flavones, and omega-3 are the most popular meat substitutes. The greatest market demand for meat substitute products is Europe, forming 39% of the world's market share in terms of revenue. Concerning potential, the Asia-Pacific market has shown a 5.3% compound annual growth rate and is the fastest-growing region owing to its huge population, increasing urbanization, and rising earnings.[1] Globally, in 2020, the meat substitute industry was worth US$20.7 billion and is forecasted to rise to US$23.2 billion by 2024, as reported by the market research company Euromonitor International.[2] Nestlé, the largest food manufacturer in the world, recently launched a Plant-Based Meal Solutions manufacturing hub in Malaysia—the first such facility in ASEAN. The company started producing a variety of new products, such as the plant-based Sensational Burger patty and also a plant-based schnitzel, both of which are made with high-grade plant-based ingredients like soy, wheat, beetroot, pomegranate, and blackcurrant.[3] Popular sneaker brands like Adidas, New Balance, and Vans have launched vegan collections that are made of environmentally friendly and ethically sourced materials.[4] The Body Shop, a major global beauty brand, expects to offer 100% vegan products with the certification of The Vegan Society's Vegan Trademark by the year 2023.[5]

The vegan trend is associated with health awareness, environmental issues, and animal welfare.[6] During the COVID-19 pandemic, the trend towards plant-based diets was further accelerated and there was evidence of an association between vegan diet and risk reduction in the severity of COVID-19.[7,8] The vegan diet is also shown to be effective in treating and preventing metabolic syndrome and cardiovascular disease because it is usually lower calorie, lower in saturated fat, and high in fiber. For many individuals, it reduces body weight, increases insulin sensitivity, promotes vasodilation, and increases triglyceride metabolism.[9] A large-scale study conducted by "Tracking Happiness" in the United States, which surveyed 11,537 respondents, showed that vegans report 7% more happiness than meat-eaters.[10] Furthermore, a widespread shift to a vegan diet can also bring benefits to the planet by fighting climate change and conserving natural resources such as water and soil. Vegan diets were reported to contribute to the most substantial reductions in greenhouse gas (GHG) emissions and land use.[11]

To our knowledge, this is the first study using a qualitative approach for studying vegan-related research (VRR) and we believe that it will complement previously published quantitative bibliometric studies on VRR.[12] This article aims to explore the VRR trend globally over 60 years with content analysis and critical review to provide a synthesis of underlying research themes and identify its future direction.

Methods

This study was registered with the local National Medical Research Register (NMRR-21-328-59004).

The procedures used in this study for the literature search and study selection were robust, transparent, and reproducible. We selected relevant VRR articles that were published between 1960 and 2020 from the Scopus database based on inclusion and exclusion criteria. Details of the literature search and study selection have been published elsewhere.[12]

Next, we performed bibliographic coupling analysis on articles that met the eligibility criteria to identify research clusters and relevant subclusters based on research themes. Bibliographically coupled studies are those in which two or more published

articles share at least one common reference or citation.[13] As a result, articles that are bibliographically coupled are more prone to have the same underlying research theme. Finally, we used conceptual or thematic content analysis with an inductive approach based on manifest content for all the included articles as a qualitative method to complement the quantitative outcome provided by bibliometric analysis. We critically reviewed the content of all included articles to provide a synthesis of underlying research themes as well as to identify the direction of future VRR. We conducted the bibliometric coupling analysis with the open-source R programming software-based Bibliometrix package.[14]

Results and Discussion

Research Clusters and The Direction of Future VRR

We broadly identified four main underlying clusters using bibliographic coupling analysis: a) consumerism, b) medical and health sciences, c) food science and technology, and d) environmental impacts. We also explored subclusters and provide relevant insights for the direction of future VRR. Figure 1 depicts the clusters and their respective subclusters. The Appendix provides specific educational points about the most important articles cited according to each cluster.

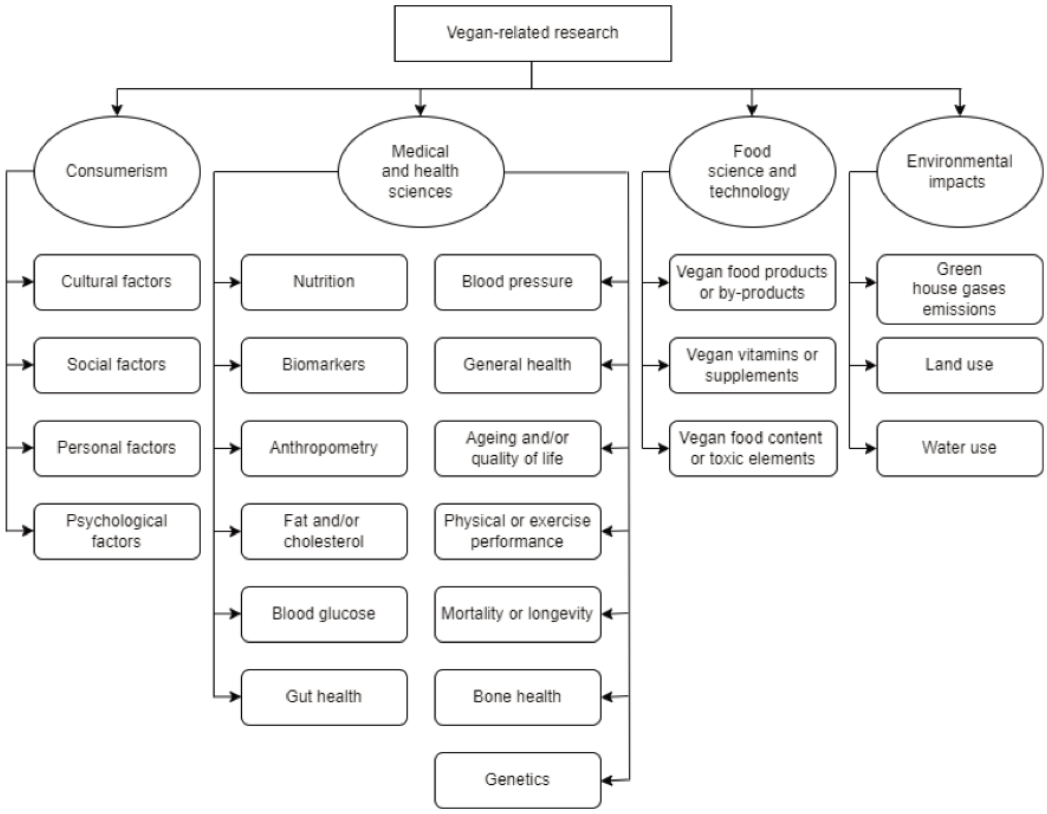

Figure 1. Clusters and their respective sub-clusters

Consumerism

We determined four subclusters under consumerism: a) cultural, b) social, c) personal, and d) psychological factors.

First, we explored the cultural factor. Religion, gender, race or ethnicity, and social class seem to be the most widely covered topics. A study regarding an Israeli vegan animal advocacy movement explores how these factors affect the movement's growth and discusses ways that vegan activists cope when confronted with these factors.[15] An au-

thor suggests that conversion to veganism can be compared to a spiritual or religious conversion, sometimes from an event in a person's life that affects the person's pathematic and sensorial spheres, and at other times from complex and slow processes affecting pragmatic and cognitive dimensions.[16] The social stigma of being vegan, especially among men, was also explored. Two articles utilized a qualitative approach to interview 20 vegan men about this matter.[17,18] Another article analyzed vegan men based on a reality television show in the United States called *Man v. Food*. The effects of patriarchal and hegemonic masculinity concerning vegan diets were examined by the authors.[19] Racism is another issue covered in VRR. One article used various sources including Facebook to interview 27 vegans of different races or ethnicity. Some of the interviewees associated veganism with whiteness and privilege. As a result, the author decided to learn how vegans of color attempt to normalize and de-stigmatize veganism in their communities.[20] A Korean study identified social class as one of the major challenges faced by the 38 interviewed participants. In Korean society, people of lower social status are usually subjected to immense social stresses, necessitating a variety of negotiation tactics to sustain a vegan diet.[21]

Social factors are also crucial in the vegan movement. Celebrities or social influencers who adopt a vegan diet serve as role models, especially when they advocate veganism as an ethical practice, and can make it more approachable for the public. However, some do not emphasize the ethical aspects of veganism which can be controversial, especially when the person ceases their vegan diet.[22] It is not uncommon for celebrities and influencers who are motivated to be vegan because of diet, weight loss, trendiness, environmental concerns, etc., to revert to a non-vegan lifestyle but it is extremely rare for an ethical vegan to cease being vegan. Family influence, especially parental influence, is strongly associated with introducing veganism to children. In 2019 and 2020, an author offered the argument that there should be no parental compromise when it comes to raising children based on the moral and ethical obligations of veganism, separate and apart from the health benefits of a vegan diet.[23,24] Political considerations and ideology factor into both the decision to adopt vegan diets and the ability to sustain that choice over time. This subject was examined in a study of over a thousand US participants, looking at the association between political ideology and the adoption of a vegan diet as well as returns to meat consumption.[25]

Age and stage of life are also two important personal factors. An author studied millennial vegans in Israel and argues that veganism helps create a generational identity through 3 interrelated practices including: a) shifting commitment from national issues to global ones, b) substituting evidence-based knowledge with other sorts of information, and c) creating consumption places that follow marketing methods to socialize practitioners into critical consumers while partaking in a youthful urban lifestyle. Millennials are thereby able to assert some authority while refraining from confronting existing political and economic structures.[26] Flexitarianism is a diet characterized by incrementalism, appealing to self-interest, with a hesitancy to define veganism as an end goal. Critics claim that flexitarians are "free-riders," free-riders being a phenomenon in the non-profit industrial complex, the term itself derived from its original use in connection with labor unions where workers who do not belong to a union still benefit from the existence of labor unions. While the goal of the vegan movement is to end animal use and abuse, flexitarians by definition do not necessarily share that goal. Yet, the professional animal rights movement still cultivates flexitarians as a financial and power resource and will promote flexitarianism despite its being squarely at odds with the stated goals of the vegan movement.[27] One author studied the personal choice of

vegans regarding eating insects. Most vegans will not eat insects because the sentience of insects is in question.[28] In addition, two German studies explored the relationship between certain personality factors including the Dark Triad personality traits and dietary preferences.[29]

The last subcluster concerns psychological factors. Among all psychological factors, concern for animals is the most studied topic in VRR and is usually discussed within the context of morality, ethics, and belief systems. An article explores the merits and flaws of Timothy Hsiao's contention that sentience is not enough for moral standing.[30] Another article considers the fact that producing vegan food results in the unavoidable death of some animals, which, on its face, seems to contradict the fundamental principle that being vegan does not cause animal harm. However, the article discusses two strategies that rationalize the deaths; one, that vegan food production results in the fewest animal deaths while the other, the doctrine of double effect, distinguishes between bringing about harm intentionally and bringing about harm merely as a foreseen consequence of one's action.[31] Using a predictive approach, an author provided insights about the power of human affection for animals and human understanding of animal minds as reasons to treat animals morally and as a basis for becoming an ethical vegan.[32] Vegan consumerism is increasingly driven by environmental concerns, too. There was a systematic review and a synthesis review that both focused on maintaining vegan diets when the motivation for being vegan is due to environmental concerns.[33,34] Health reasons also serve as a factor that motivates some to adopt vegan diets. For example, two studies that investigated orthorexia among vegans were linked to health concerns rather than to other reasons such as animal welfare, impact on the environment, and so forth.[35,36]

Future studies

Concerning cultural factors, more studies exploring the relationships between social stigma and veganism, with participants from various ethnic groups, are needed to gain a better understanding of the obstacles and successes associated with the adoption of vegan diets.[37] An author suggested further studies to evaluate the impact of high-fat vegan diets (e.g., French fries, cookies) compared with healthy vegan diets on perceptions of masculinity.[38] From a social factor perspective, more comparative investigation across a variety of media sources and over a longer period are needed to look at the impact of celebrities and social media influences on the rise of veganism.[39] Future studies should also look into other aspects of the promotional mix, such as print or television advertisements, websites, and social media marketing content, to see whether similar findings can be generalized. More studies are also needed to investigate how consumers with more divided views on meat consumption react to these appeals.[40] Further research is necessary to identify factors that promote the diffusion of vegetarian and vegan practices as a social innovation.[41] Considering personal factors, future research should look into the possible perceptual connections between in vitro and other high-tech (and thus unnaturally perceived) food alternatives.[42] More studies are needed to better understand the perspectives of those with lower educational attainment and those from different geographic areas who choose cell-based meat. Studies to better understand the fundamental reasons for the concerns about traditional and cell-based meat that have been raised in scientific literature are also needed.[43] In addition, future studies should explore the connections between subcultures and lifestyle movements in greater depth, as well as the many mechanisms of recruitment and retention of veganism as a lifestyle movement.[44] Regarding studies of those who adopt veganism due to health concerns, like orthorexia nervosa, larger sample sizes and associated risk fac-

tors are needed to warrant a conclusive statement.[45,46] In considering psychological factors, a study found that there are no significant gender variations in the strength of humanlike animal traits on the propensity to become a vegan; seeing humanlike characteristics in animals has ethical implications but its impact on the adoption of pro-animal attitudes and conduct is unknown. Thus, future research is needed to investigate and explain the causal linkages between the variables described above, as well as how gender differences may influence them.[32]

Medical and health sciences

Under this theme, most of the studies analyzed involved adults (39%), followed by babies (24%), children (22%), teenagers (9%), and, lastly, older adults (6%). There were more studies on females (56%) than males (44%). There were also a significant number of studies that specifically focused on pregnant women (21%) and athletes (17%). Generally, more studies involved subjects with poor health or health conditions (62%) than healthy people (28%); the least number of studies involved both (10%). There were also more studies about disease prevention (44%) and treatment (29%) than about diseases allegedly induced by vegan diets (26%). We noted 12 subclusters under this theme: a) nutrition; b) biomarkers; c) anthropometry; d) fat and/or cholesterol; e) blood glucose; f) gut health; g) blood pressure; h) general health, ageing, and/or quality of life; i) physical or exercise performance; j) mortality or longevity; k) bone health; and l) genetics. We further explored the two main health subclusters, nutrition and biomarkers.

Most of the articles (24%) in the health domain concern the quality of vegan diets in terms of their nutritional value, vitamins, and/or minerals. Generally, more studies focused on specific nutrients in vegan diets. This may be because vegan diets are restrictive diets and can be associated with the idea of certain nutrient deficiencies.[47] A UK cross-sectional study explored the plasma fatty acid composition in vegans, vegetarians, and meat-eaters to investigate if the proportions of eicosapentaenoic acid, docosapentaenoic acid, and docosahexaenoic acid were associated with the duration of adherence to their diets or the proportions of plasma linoleic acid and alpha-linolenic acid.[48] An Austrian study further explored the impact of those diets on the fatty acids in long-term markers such as sphingolipids, phosphatidylcholine, phosphatidylserine, phosphatidylethanolamine, as well as the sphingo- and phospholipids of erythrocytes.[49] There was also a study that explored the effect of vegan diets on the content of fatty acids in breast milk and infants' essential fatty acid status.[50] The belief that protein or acid amino insufficiency is common with vegan diets has been questioned. Vegans, vegetarians, fish-eaters, poultry-eaters, and meat-eaters from two studies, the EPIC-Oxford cohort and the UK Biobank, were assessed to determine their intake of major protein-source foods.[51,52] The EPIC-Oxford cohort supplemented their investigation to look at the variations in plasma amino acid concentrations and intakes among male individuals.[53] In a review paper, the authors looked at the protein and amino acid intakes of vegans in the west, as well as the adequacy of the diets for protein and amino acid requirements, utilizing both indirect and direct data to predict the nutritional status.[54] There were extensive studies on vitamin B12 (B12) adequacy in vegan diets too. A randomized controlled trial with healthy omnivore participants involved short-term intervention with vegan diets to ascertain B12 status with systemic biomarkers including serum B12 and holotranscobalamin.[55] Another 5-year prospective study assessed the long-term effect of vegan diets on B12 status.[56] Two studies considered the impact of maternal vegan diets by measuring breast-milk B12 concentration as well as the blood

level of B12, folic acid, ferritin, and hemoglobin in pregnant people before delivery and from the umbilical cord soon after delivery.[57,58] Lastly, 2 review papers focused on the association of B12 deficiency with vegan diets and provided recommendations to the population at risk.[59,60] Some studies approached the nutritional quality of vegan diets as a whole. A systematic review included 12 cohorts and 36 cross-sectional studies on Europeans to determine the potential for dietary deficiencies of macro- and micronutrient intakes with vegan diets in comparison to World Health Organization guidelines.[61] Another systematic review included 12 studies to assess the quality of vegetarian diets, including vegan diets and nonvegetarian diets, using the Healthy Eating Index 2010 (HEI-2010).[62] A cross-sectional online survey utilized indicators for diet quality, such as the HEI-2010 and the Mediterranean Diet Score, to compare the nutritional quality of vegan, vegetarian, semi-vegetarian, pesco-vegetarian, and omnivorous diets.[63] Similar studies were carried out to investigate the nutritional status of different dietary patterns in Finland, Poland, and Spain.[64-66] Research from the French NutriNet-Santé study also explored the nutritional values of vegan, vegetarian, and meat diets but with a link to sociodemographic characteristics added for participants from each of those diets.[67]

The second most studied topic in the health domain was biomarkers. A large cross-sectional cohort study from the UK aimed to examine the differences in hematological parameters and the prevalence of anemia between meat-eaters and vegans.[68] A similar study in Thailand looked at the pattern of 5 red blood cell parameters; namely, hematocrit, hemoglobin, mean corpuscular volume, red blood cell distribution width, and lower mean corpuscular haemoglobin.[69] Another study to explore blood parameters involved 53 healthy omnivore participants. Following a one-week pre-treatment phase of a controlled mixed diet, individuals were randomly assigned to either a vegan or meat diet for 4 weeks. To investigate the effect of vegan diets on rheumatoid arthritis, the study included secondary parameters like amino acid serum levels, granulocytes and monocytes colony-stimulating factor serum levels as well as the routine immune parameters used in individuals with rheumatoid arthritis.[70] Vegan diets are inversely associated with inflammation markers and this is linked with many health benefits.[71] A systematic review and meta-analysis examined the differences between vegan diets and omnivore diets concerning inflammatory biomarkers including C-reactive protein, interleukin-6, interleukin-18, interleukin-1 receptor antagonist, tumor necrosis factor-alpha, E-selectin, intercellular adhesion molecule-1, monocyte chemoattractant protein-1, adiponectin, omentin-1, and resistin.[72] A similar study measuring different types of biomarkers of antioxidant status and oxidative stress like malondialdehyde, hydrogen peroxide, nitrate/nitrite, Trolox equivalent antioxidant capacity, and oxygen radical absorbance capacity was conducted on 43 individuals using the Daniel Fast.[73] The Daniel Fast is a 21-day diet plan based on the biblical book of Daniel. It involves following a strict vegan diet for 21 days.[74] Studies related to diabetes were common, too. The effects of a vegan diet versus a conventional diet on changes in thalamus perfusion, gastrointestinal hormones, and satiety in type 2 diabetes individuals were studied using a randomized crossover design.[75] A further study looked at the mitochondrial density and intramyocellular lipid content of vegans due to the low incidence of insulin resistance-associated diseases and higher insulin sensitivity among vegans.[76] Meat consumption and high-fat diets are highly linked to colorectal cancer, but vegan diets with high fiber consumption have the opposite effect.[77] As fecal bile acids may be linked to an increased risk of colorectal cancer, there was a cross-sectional study to investigate the amount of fecal and serum bile acids in 36 vegans and 36 omnivores.[78] As renal diseases are a leading cause of mortality and Taiwan has the highest incidence of end-stage renal disease globally, a local

study was conducted to explore dietary protein on renal function in 102 Buddhist nuns and an equal number of omnivores.[79] Insulin resistance, hepatic dysfunction, and cardiometabolic risk are all examples of metabolic disorders that are associated with high potential renal acid load. A trial measured the 1-week change in the acid load and urine pH of healthy adults from a campus population who followed a vegan diet for either 2, 3, or 7 days. This aided in the investigation of the effects of vegan diets on the acid-base balance among healthy adults.[80] In addition, because uric acid is usually associated with animal protein diets and not many studies compare the level of uric acid in diets with plant-based protein, the EPIC-Oxford cohort examined the differences in uric acid levels in the blood of 424 meat eaters, 425 fish eaters, 422 vegetarians, and 422 vegans.[81] In the context of breast cancer, a study was performed to investigate if certain long-term dietary patterns manifest a different impact on pituitary functions. Plasma prolactin and growth hormone level were measured by radioimmunoassay in 47 premenopausal volunteers.[82] Prostate cancer is usually associated with high levels of insulin-like growth factor (IGF) I and low levels of some of its binding proteins (IGFBPs). In the Prostate Cancer Lifestyle Trial, prostate cancer patients who underwent comprehensive lifestyle changes, including a very low-fat vegan diet supplemented with soy protein (58 g/day), were assessed by their dietary intakes of total protein and soy isoflavones concerning the IGF axis.[83] In order to understand the rates of cancer, a similar study was done to examine the associations of diet with serum IGF-I and IGFBPs among 292 British women (92 vegan, 101 vegetarians, and 99 meat-eaters) aged 20–70 years.[84] A study from Poland was carried out to determine how a vegan diet affects exocrine pancreatic secretion since, at the time of the study, there was no evidence of a link between relative and non-relative changes in energy and nutrient consumption with pancreatic secretion. The 6-week study involved 21 healthy omnivores. The nutrient intake and fecal output of pancreatic enzymes (elastase-1, chymotrypsin and lipase) were measured twice during the study.[85] Lastly, a study was done using H-nuclear magnetic resonance spectroscopy to measure the postprandial metabolic response to having a meal at breakfast that was either vegan, lacto-ovo-vegetarian, or omnivore. The study is crucial as nutritional metabolomics provide an unbiased technique for investigating how the human metabolome is modulated concerning food intake.[86]

Future studies

To offer meaningful recommendations about the adoption of vegan diets, larger and longer-term randomized controlled trials on the impact of vegan diets on neurological and cognitive functions, obesity, diabetes, longevity, and other cardiovascular outcomes are warranted.[87,88] More research is needed to better understand the intricate mechanisms and interrelationships between vegan diets and gut microbiota. The employment of culture-independent molecular approaches is needed, and databases need to be constructed to determine "healthy" gut microbiota compositions and how vegan diets affect the gut microbiota. Furthermore, more disease-specific genomes in the gut microbiota can be investigated by utilizing novel approaches such as metagenomics, metatranscriptomics, metaproteomics, and metabolomics to identify the effect of vegan diets.[89] Because no prospective study has looked at the effects of vegan diets on nephrolithiasis risk factors, more research is needed to determine the optimum diet for various kidney stone morphologies.[90] More studies are also needed to see if vegan diets can help patients avoid poor cancer-related outcomes before and/or after a cancer diagnosis. This will help to develop dietary guidelines for cancer survivors.[91] As a pilot study of raw vegan diets was linked with improved quality of life, future study is war-

ranted to assess the impact of such a diet with clinical trials on healthy people and people with health conditions.[92] Despite the many advantages of a vegan diet, additional research on its practical use, impacts, and safety are required both in adults and children.[93,94] More research is also needed to control for confounding factors in order to determine if a vegan diet or rather the health consciousness associated with a vegan diet is the major contributor to these health benefits.[62]

Food science and technology

The food science and technology cluster encompass articles that demonstrated vegan food or ingredients as a substitute or alternative to those from animal sources. Under this theme, we identified three subclusters including a) vegan food products or by-products, b) vegan vitamins or supplements, and c) vegan food content or toxic elements.

Firstly, regarding vegan food products or by-products, there are more people who prefer mindful eating than people who do not, including consumers who have allergies or who are vegans. The demand for conventional food substitutes or alternatives is on the rise. An article from 1998 presented a variety of vegan substitutes for dairy products including vegan cream, cheese, yoghurt, ice cream, and margarine.[95] Among all, vegan beverages, particularly vegan milk as a non-dairy milk alternative, are the most common vegan food products sought by consumers. A review paper classified milk alternatives from plant sources into 5 categories, namely cereal-based, legume-based, nut-based, seed-based, and pseudo-cereal-based. The authors also looked into currently available technological interventions to improve the quality and acceptability of plant-based milks in terms of product stability, elimination or reduction of off-flavors, inactivation or removal of inhibitors like trypsin, phytates acid and saponins, product shelf life, nutritional value, and palatability.[96] Some studies focused on analyzing the development process of plant protein beverages. One study investigated the formulation and processing conditions necessary to produce vegan beverages based on protein amaranth, a perennial plant, in order to ensure that they are physically good, stable, and microbiologically safe.[97] Another study involved Brazil nut powdered milk to assess its processing yield.[98] Vegan probiotic food products were gaining attention, too. Because people are becoming more aware of the significance of gut microbiome, the development of various matrices for delivering vegan probiotics, including cereals and vegetable and fruit juices, has been spurred by rising demand. A study was designed to create a ready-to-drink locally-sourced probiotic oat milk drink fermented with micro-encapsulated *Lactobacillus plantarum* that has therapeutic characteristics and is served as an alternative to dairy milk.[99] Kefir, a fermented beverage, is another good source of probiotic microorganisms. It is traditionally dairy based but vegan versions are gaining attention. One study explored the development of vegan kefir by comparing 3 different mediums, soybean hydrolyzed extract, colostrum, and honey, on the outcome of DNA protection and antioxidant activities.[100] Another study investigated the use of flaxseed oil cake in the fermenting process by measuring microbial population changes, pH, acidity, protein levels, polyphenolics, flavonoids, ascorbic acid, and so forth.[101] Other fermentation substrates like yam, sesame, and white bean extracts were investigated. The kinetics of fermentation, chemical content, and color of the extracts of these substrates were all studied.[102] A review provided insight on a comparable microbiological association of a sugary kefir beverage with typical dairy kefir fermentation, especially among lactic acid bacteria and yeast species such *as Lactobacillus, Leuconostoc, Kluyveromyces, Pichia,* and *Saccharomyces.*[103] In addition, a review based on 42 articles offered a discussion on the effects of lactic acid bacteria in fermented fruit and vegetable

juices.[104] Two studies explored the use of coconut to develop non-dairy functional cultured beverages and reduced-fat yogurt.[105,106] Ice cream was studied too. Two vegan ice cream formulations—one made from potatoes and one from inulin— were compared to 3 traditional ice creams containing milk protein in order to determine the ice recrystallisation for structural and texture characteristics as well as the behavior during melting.[107] Amaranth protein was explored for its use in lemon sorbet production.[108] Amaranth flour was also analyzed for its potential use in producing gluten-free cookies with antithrombotic and antihypertensive activity.[109] A study discussed the production and use of a variety of meat alternatives as protein sources including soy, wheat, pea, and mycoprotein and compared their relative nutrient profiles with meat.[110] Next, Arabic gum was investigated to estimate its antimicrobial and antioxidant properties for the development of vegan "egg-free" mayonnaise.[111] Lastly, 2 studies explored the foaming properties of aquafaba. One study investigated the various factors that affect the foam characteristics of aquafaba from lima bean and ways to utilize it in eggless cupcakes while another study examined aquafaba from canned chickpeas as a possible egg substitute in the creation of vegan mayonnaise.[112,113]

As vitamin B12 deficiency was commonly associated with vegan diets, research regarding the development of vegan B12 supplements gained some attention in VRR. Researchers studied the *Propionibacterium freudenreichii subsp. Shermanii* bacteria obtained from agroindustry remnants, the liquid acid protein residue of soybean, as a low-cost vegan culture medium to examine the production of B12 by potential probiotic bacteria.[114] Tempeh, a fungal fermented soybean protein, contains an amount of B12 that is insufficient to meet the required daily consumption.[115] There were two studies that focused on boosting B12 content in tempeh by using lupin beans with *Rhizopus oligosporus* and *Propionibacterium freudenreichii* cofermentation.[116,117] Another common VRR topic concerned the development of omega-3 fatty acid alternatives. A study aimed to create and define a highly polyunsaturated flaxseed oil powder that could serve as a good source of omega-3 fatty acid in vegan diets.[118] Another study focused on techniques to create omega-3 fatty acids from flaxseed and algal oils in water nanoemulsions that may be utilized in functional foods.[119] *Eleutherococcus* fruits, which are high in protein and low calorie were investigated to determine the immuno-nutrition, mineral, and fatty acid composition, as well as the total phenolics and flavonoids content.[120]

Due to industrialization, heavy metals and metallic compounds travel through the food chain to people and animals, posing a health risk via soil, water, and air. Using inductively coupled plasma-optic emission spectroscopy, the amounts of trace and major elements in commercial vegan milk and oil samples (soybean milk, coconut milk, almond milk, soybean oil, bitter almond oil, almond oil, coconut oil, walnut oil) collected from Turkish supermarkets were investigated.[121] Algae—important nutrition sources among vegans—have a high capacity to absorb and accumulate toxic metals.[122] Researchers evaluated the levels of toxic metals such as lead, cadmium, arsenic, and mercury in edible seaweed samples sold in Spain to estimate the toxicological risk associated with their use.[123] Dioxins, dibenzofurans, and polychlorinated biphenyls which are synthetic, poisonous, and extremely persistent compounds are other common food contaminants. Their concentrations were determined from food samples, including a simulated vegan diet, that were all obtained from food supermarkets across five regions in the United States.[124] Mycotoxin, with its teratogenic, mutagenic, carcinogenic, and/or immunomodulatory properties was studied in France. Aflatoxins, ochratoxin A, trichothecenes, zearalenone, fumonisins, and patulin were examined in French diets, including vegan diets.[125] While there is mounting evidence that taurine

is an important nutrient, vegans often have taurine deficiency.[126] The taurine content in 48 plant sources from vegetables, fruits, nuts, seeds, and grains was measured.[127]

Future studies

In the production of non-dairy probiotics, prebiotics, and synbiotic beverages, the use of microencapsulation to ease food processing while also avoiding probiotic degradation should be studied by researchers. Nanotechnology has the potential to open new avenues for synbiotic applications too. Although the commercial use of nano-encapsulated probiotics is currently evolving, precautions for their use on humans are still required.[128] In future years, concerted research activities will likely create a nutritionally complete vegan beverage with good overall acceptance that is both pleasant and nutritionally sufficient by using improved processing, technological interventions, and fortification approaches.[96] Alternative resources for making vegan milk such as Brazil nut milk powder require further study to improve its production, reduce harmful or unwanted content, and extend its product shelf life. Research on the functional features of the product peptides is required too.[98]

Environmental impacts

Diet and food production impacts planetary health. Environmental impacts are expected to worsen in the absence of vigorous risk reduction measures. This is because demand for foods such as meat and dairy, with higher environmental implications, is expected to surge with an increasing global population in the coming years.[129] Therefore, sustainable diets like vegan diets might address the growing environmental risks associated with food production and consumption. We identified 3 subclusters of environmental impacts: a) greenhouse gas (GHG) emissions, b) land use, and c) water use. Since these subclusters were presented together in most of the articles analyzed, we will discuss them together to provide a more comprehensive view of their presence in VRR.

One study analyzed with modelling analysis on more than 150 countries to determine the environmental impact of reducing animal-sourced foods. To examine the link between the health and environmental consequences of dietary changes, researchers integrated country-specific and food-group-specific footprints for GHG emissions, as well as demands for cropland and freshwater use.[130] A review article included 21 studies and examined 66 dietary choices, including vegan diets, to explore the differences in carbon footprints of each in order to identify sustainable diets.[131] On the other hand, a systematic review that emphasized only vegan, vegetarian, and omnivorous diets included 16 studies and 18 reviews. Researchers engaged the life cycle impact assessment technique to estimate GHG emissions and land and water use.[132] Another research effort involved 29,210 participants from the NutriNet-Santé study to evaluate the environmental effects of omnivorous, pesco-vegetarian, vegetarian, and vegan diets on GHG emissions and land occupation while factoring in the form of agricultural methods (organic or conventional) used in food production.[133] Another study focused on only 2 diets, namely Mediterranean and vegan diets, calculated the total global warming potential impact and regional biodiversity impact due to land use.[134] One study looked at a biophysically feasible option space of 313 global food-system scenarios in a hypothetical no-deforestation world of 2050. The study quantified GHG emissions, recognized interconnections between food supply, agricultural concentration, and livestock raising in the option space, as well as distinguished diets with low-GHG based on those assumptions.[135]

Future studies

The scientific study of environmental nutrition and sustainable diets is still in its early

stages. To gain a more thorough knowledge of the sustainability of food habits, scientists should consider other local or global environmental concerns with diets, such as air pollution, temperature increase, ozone layer damage, deforestation, and biodiversity disappearance. Other environmental variables, such as ecotoxicity implications, nitrate and pesticide leaching, as well as soil quality should be included in future studies. Only a comprehensive and holistic evaluation will allow us to examine the effects of diet on the environment on a larger scale. Additionally, environmental indicators to differentiate among various agricultural techniques are still limited, highlighting the need for additional studies in this area in order to undertake a more comprehensive assessment.[133] Livestock raising is unsustainable. However, further research is needed to provide solutions or greener business alternatives for those who are already involved, especially for small-scale family farms. Such family farms depend heavily on raising animals for meat and dairy production, as well as for the labor the animals provide in the operation of the farm. There are various types of plant-based diets. Most studies on the environmental impacts have employed average eating patterns of those diets. As a result, it is plausible that those averages conceal significant disparities among specific plant-based diets. There is a need for more research into the different types of plant-based diets to identify the environmental sustainability effects of each diet.[136]

Limitation

We included only English articles from the Scopus database. Articles in other languages and from other databases like the Web of Sciences may have provided a more inclusive approach. Since the article includes studies published over a span of 60 years, the high number of articles cited in this article was necessary. However, this also means it was not possible to provide a lot of detail on each article and how they can potentially be leveraged by those looking to further VRR. Lastly, in doing this bibliometric review, we did not evaluate the bias, if any, of the underlying articles. Therefore, a future study may consider whether to include a subjective analysis of possible bias in source articles.

Conclusion

We presented a bibliometric review and suggestions for the direction of future VRR with a qualitative approach. We identified 4 clusters with their associated subclusters: a) consumerism (cultural, social, personal, and psychological factors), b) medical and health sciences (nutrition, biomarkers, anthropometry, fat and/or cholesterol, blood glucose, gut health, blood pressure, general health, ageing and/or quality of life, physical or exercise performance, mortality or longevity, bone health, and genetics), c) food science and technology (vegan food products or by-products, vegan vitamins or supplements, and vegan food content or toxic elements), and d) environmental impacts (GHG emissions, land and water use).

The findings of this study have several academic and industry implications. For scholars and academic practitioners interested in VRR, it provides a wide-ranging overview of research domains and introduces readers to key studies, concepts, and methods. Animal advocates and vegan societies can also use this information to improve their organizations and resources and to influence the future direction of their organizations. All of these are essential because the collective food habits and lifestyles of a civilization have a significant impact on climate change and have other environmental consequences. Other than the beneficial health effects of vegan diets, there is widespread agreement that adopting veganism is critical for preserving the planet. In short, veganism has the potential to help resolve critical diet-health-environment issues facing us

today. We propose more research focused on the various aspects covered in this article to provide more comprehensive knowledge for effective policy prescriptions.

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Appendix: The most important articles cited according to each cluster

Cluster	The most important articles cited	Specific educational point
Consumerism	Orthorexic and restrained eating behavior in vegans, vegetarians, and individuals on a diet[46]	The goal of this study was to examine orthorexic and restraint eating behaviors among vegans and vegetarians as well as those on a weight-loss diet. The Düsseldorfer Orthorexie Skala was used to examine orthorexic eating behaviors, while the Restraint Eating Scale was used to examine restraint eating behaviors. The study concluded that someone with restraint eating behaviors, whether for ethical or weight-loss reasons, exhibits greater orthorexic eating behaviors than those without.
Medical and health sciences	Comparison of nutritional quality of the vegan, vegetarian, semi-vegetarian, pesco-vegetarian and omnivorous diet[63]	There are a few studies that compare the nutritional quality of restrictive diets, particularly vegan diets. The goal of this study was to look at vegan, vegetarian, semi-vegetarian, pesco-vegetarian, and omnivorous diets to examine their nutritional quality and contributing components. This cross-sectional online study used a 52-item food frequency questionnaire to estimate dietary intake while the Mediterranean Diet Score and the Healthy Eating Index 2010 were used as diet quality indicators. The study concluded that the vegan diet is the healthiest. However, because people on restrictive diets are often more health-conscious than the general population, adequate attention should be paid to possible confounders of the index scores and health outcomes. Finally, blood tests combined with specific questions on supplements/fortified products used in vegan diets may reveal whether a high index score encompasses all components of a wholesome diet.
Food science and technology	Plant-based milk alternatives an emerging segment of functional beverages: A review[96]	This study provides a review on plant-based milk alternatives including cereal-based, legume-based, nut-based, seed-based, and pseudo-cereal-based milk alternatives. The paper looked at each plant-based milk alternative's a) functional elements and nutritional benefits, b) major barrier in acceptance and technological innovation to solve the problem (enhancing product stability, removing off-flavor, inactivation/removal of inhibitors such as trypsin, phytic acid, and saponins, as well as shelf-life optimization), c) combining for nutritional balance and sensory acceptability, d) nutritional fortification, and e) requirements for labelling and commercialization. Accordingly, plant-based milk alternatives represent a huge growth opportunity for the health food market and should be thoroughly investigated via the integration of innovative processing, technological innovation, and fortification processes to produce a nutritionally balanced beverage with relatively high consumer acceptance.
Environmental impacts	Health and nutritional aspects of sustainable diet strategies and their association with environmental impacts: A global modelling analysis with country-level detail[130]	The study looked at three diet scenarios motivated by environmental, food security, and public health goals with an integrated global modelling framework of health and environment that involved more than 150 nations. The modelling framework for the 3 sets of approaches comprises merged analyses of environmental effects, nutritional levels, and death due to diet- and weight-related chronic diseases. In relation to the environmental goal, the first set substituted 25–100% of animal-based foods with plant-based foods. In the second set, which was focused on food security and improving energy balance, the levels of underweight, overweight, and obesity were reduced by several increments of energy intake (kcal). The final set included 4 energy-balanced eating patterns based on public health goals: flexitarian, pescatarian, vegetarian, and vegan. The study concluded that sustainable diets could result in simultaneous declines in environmental and health consequences globally and regionally, especially in high- and middle-income nations, with an additional increase in resource use among low-income countries when diets vary. The authors suggest that updating national dietary standards to match the most recent scientific evidence on healthy eating could be beneficial in and of itself for improving health and decreasing environmental consequences, and could be used to supplement larger and more specific sustainability requirements.