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A Bibliometric analysis of research on stability of functional beverages by use of hydrocolloids using VOSviewer mapping analysis computations

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This article presents a scientific overview of studies on the stabilization of functional beverages in relation to the use of hydrocolloids globally, an emerging yet expanding association that has developed through time and been systematized since 1963. A bibliometric analysis based on data from 717 records was used for examining the extracted articles after the screening from databases in Scopus, Web of Science core collection and Dimensions.ai between 2002 and 2022, using VOSviewer. The outcomes included publications on use of hydrocolloids in stabilization of functional beverages were significantly increased, globally after 2017. China, Brazil, Iran, and United states were the most efficient providers of research that played a prominent part in collaborative research on the inclusion of stabilizers in functional beverages. The study also focuses on highly cited articles addressing the application of hydrocolloids in stabilization had been identified in several substantially cited publications. The journal co-citations revealed 75 specific journals and co-citation between cited references obtained a result of 134 cited references mainly published in Food Hydrocolloids and Food Chemistry. The co-occurrence of keywords that appeared extensively were offering evidence of a progression that permits for the rise of competing hypotheses on the implications of the use of hydrocolloids in the stabilization of functional beverages.

Keywords: stabilization; hydrocolloids; functional beverages; bibliometric analysis; VOSviewer

Introduction

Functional beverages have emerged decisively in popularity over the past decade due to their distinctive and inherent health benefits. However, a significant issue for the preservation of fruit juices turbidity over storage time is the stabilization of beverages pasteurization merely is ineffective in preventing cloud loss, which has been primarily correlated with pectic enzyme action and, particularly, to pectin esterase activity on cloud-stabilizing pectin, resulting in pectinic acids and pectic acids that precipitate with calcium ions present in juices that are consumed (Demirdöven & Baysal, 2014) (Demirdöven & Baysal, 2014). Studies revealed that proteins with phenol compounds are the main components responsible for the turbidity of clear fruit juices due to the fact that phenolic compounds are extremely unstable and frequently oxidize during storage, they can form accumulates and lose their solubility (Esteruelas *et al*., 2011). Additionally, studies have shown that native phenolic compounds do not cause turbidity; rather, their oxidized metabolites can accumulate or combine with proteins to cause accumulation and flocculation, which may result in sediment (Millet *et al*., 2017). (Zeng *et al*., 2019) claims that despite the fact that the browning, delamination, and precipitation that occur in the hazy juice mechanism during storage have no effect on the juice's flavour. As the pulp in bottled beverages gets sedimented which is regarded as a quality defect, the stabilization of sediment and cloudy fruit juices is a prerequisite for sensory and consumer acceptance in addition to enhancing the visual appeal of the beverage (Ellerbee & Wicker, 2011).

In fruit juices and other bottled beverages like squashes, nectars, and crush, pulp particulate have a tendency to coalesce and eventually settle out of the continuous phase, leaving behind an opaque, flavorless, and possibly undesirable sediment at the bottom of the storage bottles i.e., insoluble phase (the pulp) dispersed in a viscous solution (the serum).“Fruit tissue cells and their cell walls, fragments, and insoluble polymer masses and chains make up the dispersed phase, or pulp. The serum is an aqueous mixture of soluble polysaccharides, carbohydrates, acids and salts (Augusto *et al*.,

2012).”The stability of cloudy beverages depends on the juice's granularity in addition to the components of the two phases (Wellala *et al*., 2020).“The possibilities of sedimentation during storage is lesser for cloud particles of 2 μm and smaller, which also form more stable suspensions than large particles (Zhang *et al*., 2023).”The particle sedimentation velocity, according to Stokes Law, is proportional to the size of the particle (diameter) of the juice and the disparity in densities between the particles and the dispersion media. Viscosity of the dispersed media has an inverse relationship with size of the particle (Salehi, 2020). As a result, an upsurge in the continuous phase's viscosity eventually leads to a decrease in the rate of sedimentation (Sinchaipanit *et al*., 2013). According to prior research, an interaction of hydrogen bonding, covalent and ionic bonding, hydrophobic action and van der Waals forces predominantly contributes to the sedimentation of beverages (Siebert, 2006);(Yang *et al*., 2020). At present, only few reported studies showed the key reason for sedimentation in bottled beverages in the industry (Qu *et al*., 2021).

The primary industrial procedure for reducing fluid particle size and creating emulsions is homogenization. The applications of hydrophilic colloids (hydrocolloids or food gums) are an additional approach to increase the long-term stability of ready-to-drink beverages. As a consequence of their ability to hold water and alter the rheological characteristics of solutions, hydrocolloids are polysaccharides utilized in the food and beverage industry (Sinchaipanit *et al*., 2013).“They are applied to food products like beverages, ice cream, sauces and instant foods functioning as gelling agents, stabilizers, thickeners or providers of a certain texture and mouth feel (Karaman *et al*., 2014).” The intent of stabilizers is to increase viscosity to improve flavour and provide flow to a beverage. Additionally, they maintain emulsification, which prevents sedimentation by keeping other components suspended in the finished product and making sure the nutraceutical component remains suspended. Studies have demonstrated that the interaction of protein-polysaccharides and the resultant impact of minerals can result in turbidity and sediment in plant-based beverages (Mousavi *et al*., 2020); (Wang *et al*., 2020).“Since juice particles also have a negative electrical charge, some hydrocolloids that are negatively charged, such as pectin or carboxy-methylcellulose, stabilize juice particles by enhancing the inter-particle repulsive interactions (Staubmann *et al*., 2023).”The stabilizing property of hydrocolloids is determined by their surface charge or zeta potential. Within the dispersion, particles repel one another more vigorously, the higher their zeta potential (positive or negative) (YuJun *et al*., 2019). In the area of beverage manufacturing, beverage sediment is an emerging area of challenge, and how it interacts of the chemical components in plants acts as an essential part in the production of beverages sediment. However, it has been observed that hydrocolloids improve the viscosity, cloud stability and appearance of fruit juices and beverages, significant and comprehensive investigation on the prevention of sediment and cloud particles of beverages is still unattainable. Bibliometric visualization analysis will allow evaluation of the current research activities with regards to stabilization of beverage industry by means of hydrocolloids, forecasts of the specific contribution of different countries, and will shed light on future development directions in this area, this can be accomplished because there is an abundance of literature available on the strategic application of hydrocolloids in functional beverages. As an impartial way to assess scientific literature that improves rigor and reduces research bias, the bibliometric method is especially pertinent for achieving that objective (Zupic & Čater, 2015);(Sweileh, 2020). This manuscript addresses this research gap by using bibliometric analysis to understand the causes of the sedimentation of plant-based beverages, followed by the application of hydrocolloids to solve the issues faced by the beverage industry through an analysis of research progress with the field, the most significant publications and a content analysis of the key themes in the field. The approach has grown significantly in a purpose for assessing the research and productivity among professionals at community level (Ellegaard & Wallin, 2015).

Method and materials

The bibliometric methodology encompasses the use of quantitative tools on bibliometric data and summarizes the bibliometric and intellectual structure of a topic by examining the connections between multiple research components (Donthu *et al*., 2021). This information can be used to highlight the contributions of particular fields of study, spot intersections and data silos, as well as trends and prospective gaps(Block & Fisch, 2020). As a result, it

offers both a science mapping and a performance analysis that aid in determining how an area of study has evolved thematically (Fadden *et al*., 2021); (Cobo *et al*., 2011).

In this study, a procedure was designed for selecting the search terms, determining the right database, defining the search criteria, choosing the software for analysis, and evaluating the outcomes. The methodology employed in this paper was developed using the Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) framework (Moher *et al*., 2009), as presented in Figure 1.

Database Selection

"For an ideal bibliometric study, different databases need to be used to retrieve the relevant documents to ensure the comprehensiveness of the analysis. However, the use of multiple databases is applicable when the volume of literature on the investigated topic is limited."In the current study, "Scopus and (WoS) Web of Science core collection and Dimensions.ai database was used to retrieve relevant articles and data because of the least volume of literature on the least investigated topic."

More than 23,000 journals across all scientific subjects are indexed in Scopus, which is much larger than the Web of Science (Falagas *et al*., 2008). Additionally, it is simple to export data from Scopus to other applications. Scopus has two search options: a simple search and an advanced search, where extensive and complex search queries can be used to successfully complete an objective. Search phrases can be entered into Scopus using terms found in titles, titles/abstracts, journal names, author names, and affiliations.

Web of Science has several benefits that make it appropriate for bibliometric analysis. "WoS is a comprehensive database that covers the wide range of fields under evaluation and is widely used in the bibliometric analysis (Pranckutė, 2021); (Fadden *et al*., 2021);(Montero *et al*., 2018)."Due to its disciplinary coverage, quality criteria, and tools for data extraction/visualization, "the (WoS) Web of Science core collection was specifically chosen."

Dimensions.ai, a connected research information system offered by Digital Science (https://www.dimensions.ai), is the source of the data. This system was selected for its vast amount of data, which includes the number of citations per article, as well as the fact that it gives an API that enables searches using a certain DSL (Domain Specific Language) (García-Sánchez *et al*., 2019).

Search Strategy

Creating an effective search strategy with high accuracy is one of the prerequisites for scientometric analysis in order to acquire thorough findings and analysis. "This study developed queries on the topic of stability of functional beverages by doing a pre-review of both gray literature and scientific publications to

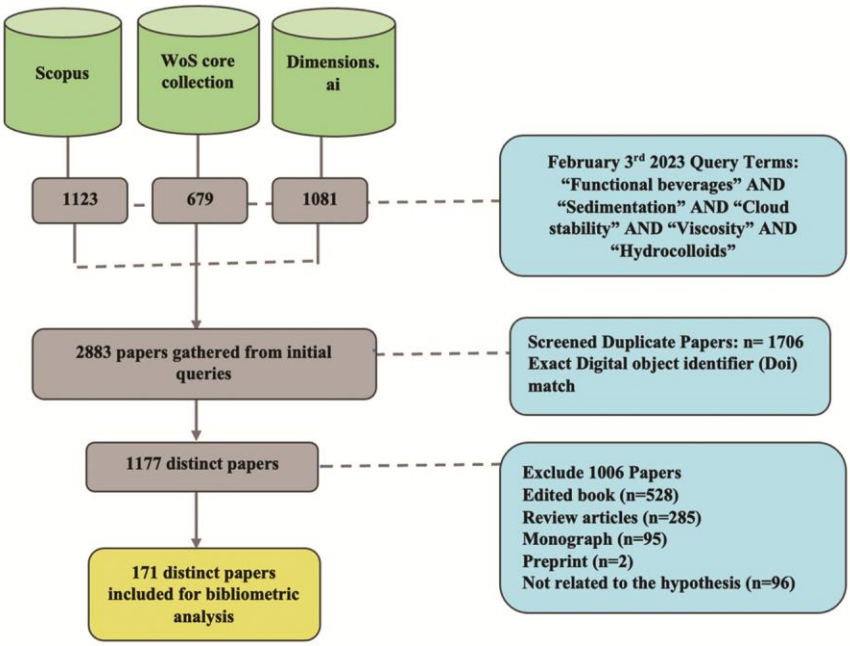

Fig. 1 — PRISMA diagram showing our literature search inclusion process

compile some search phrases as advised by (Sweileh & Moh'd Mansour, 2020)"who conducted a bibliometric analysis on hydrocolloids used in juices and functional beverages. The specific searches were TS= ((("functional beverages") and ("sedimentation") and ("cloud stability") and ("viscosity") and ("hydrocolloids")).

"Refining Results Retrieved from the Search"

"The cross checking of the searched results through screening and eligibility analysis for duplicates led to exclusion of 1706 and inclusion of 1177 out of total 2883 documents. The further search restricted to exclusively journal articles to focus more on original research, resulted to 171 journal articles, used for the final bibliometric analysis. The study period was 2002 to 2022, though initial evaluations showed limited research before the year 2000. Language restrictions were not imposed."

Data Export and Analysis

"Retrieved data were exported from Scopus, (WoS) Web of Science core collection and Dimensions.ai in (CSV) format, which included bibliographical information such as titles, abstracts, journals, authors, institutions, publication years and keywords and for further analysis and visualization using Microsoft Excel 2021 and bibliometric analysis software."The visualization maps were produced using the VOS viewer software."Different inter-relationships between the articles, the nations and institutions of their co-citations, origin, and authors were displayed using the linkage strengths from the maps. A greater association of the evaluation feature was indicated by a thicker connecting line and a higher value for the link (van Eck & Waltman, 2011).This study used a number of bibliometric parameters, such as 1) growth in publishing over the evaluation period and citation analysis, 2) most productive countries and highly cited articles pertinent to the search query, 3) the most effective journals, authors, references cited and keywords 4) co-citations.

Results and discussion

"Growth of publications and citation analysis"

An upsurge in the yearly sum of publications was observed subsequently 2017, in accordance with the analysis. With the mean citation report for each year, the total number of publications increased annually (Figure 2). The 10 most highly cited articles addressing the application of stabilizers in functional beverages had been identified in substantially cited publications, which are recorded in Table 1."Notably, the first top rank article had 214 citations and this study reported the desirable orange beverage emulsion was obtained by combined level of 10.78% (w/w) Arabic gum, 0.24% (w/w) xanthan gum and 12.43% (w/w) orange oil (Mirhosseini *et al*., 2008)."Despite the fact that the findings indicated a common upward inclination in current years (particularly in the fields of food hydrocolloids, food chemistry and, food engineering), numerous countries continue to lag behind in the depth of research being done on the stabilization of functional beverages.

Highest constructive countries

The aggregate sum of publications related to application of stabilizers in functional beverages was generated by 37 countries. China was the highest constructive of research (n = 34) followed by Iran (n = 20), United States (n = 16), and then Brazil (n = 10). Furthermore, built on the total number of citations per article, the United States ranked first

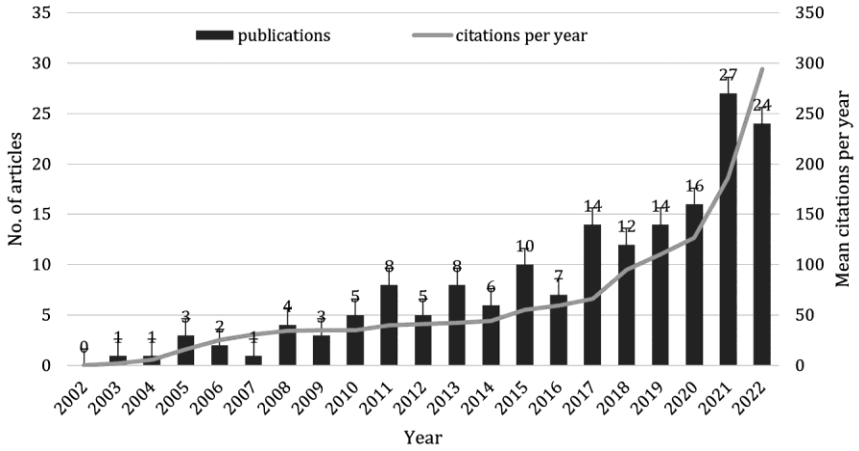

Fig. 2 — "Annual growth of the number of focused publications on stability of functional beverages"and mean of total citations per year"

Table 1 — "Highly cited articles on application of stabilizers in functional beverages"

Author, year	Document title and journal name	Total number of citations
(Mirhosseini *et al*., 2008)	"Effect of Arabic gum, xanthan gum and orange oil contents on ζ-potential, conductivity, stability, size index and pH of orange beverage emulsion, *Colloids and Surfaces a Physicochemical and Engineering Aspects"*	214
(Rojas *et al*., 2016)	"Peach juice processed by the ultrasound technology: Changes in its microstructure improve its physical properties and stability, *Food Research International"*	124
(A. R. Taherian *et al*., 2006)	"Effect of added oil and modified starch on rheological properties, droplet size distribution, opacity and stability of beverage cloud emulsions, *Journal of Food Engineering"*	108
(Lacroix *et al*., 2005)	"Inactivation of pectin methylesterase and stabilization of opalescence in orange juice by dynamic high pressure, *Food Research International"*	98
(Klein *et al*., 2010)	"Enhanced stabilization of cloudy emulsions with gum Arabic and whey protein isolate, *Colloids and Surfaces B Biointerfaces"*	96
(Hosseini *et al*., 2015)	"Application of image processing to assess emulsion stability and emulsification properties of Arabic gum, *Carbohydrate Polymers"*	94
(Cruz-Cansino *et al*., 2015)	"Shelf life, physicochemical, microbiological and antioxidant properties of purple cactus pear (Opuntia ficus indica) juice after thermoultrasound treatment, *Ultrasonics Sonochemistry"*	89
(Silva *et al*., 2010)	"The effect of homogenisation on the stability of pineapple pulp, *International Journal of Food Science & Technology"*	87
(Mikkonen *et al*., 2009)	"Mannans as stabilizers of oil-in-water beverage emulsions, *LWT"*	73
(Ibrahim *et al*., 2011)	"Effect of clouding agents on the quality of apple juice during storage, *Food Hydrocolloids"*	50

↑Only top 10 articles are presented here

Table 2 — Top 10 countries with productive documents related to application of stabilizers in functional beverages

Country (n=37)	Total number of research articles	α of all research articles (n=37)	Total number of citations
China	34	91.9	805
Iran	20	54.1	715
United States	16	43.2	1218
Brazil	10	27.0	523
India	9	24.3	722
Malaysia	9	24.3	457
Canada	6	16.2	403
France	6	16.2	173
Germany	6	16.2	137
New Zealand	6	16.2	141

↑Only top 10 countries are presented here

(n = 1218) then China (n = 805) and India (n = 722). Furthermore, the United States, China, India, Iran and Brazil were found to be the top influential countries in terms of number of citations (Table 2).

"Co-citation analysis and cited sources"

A similar study of journal co-citations was conducted with a minimum threshold of 20 citations, and the findings are shown in Figure 3. "Explicitly, this procedure yielded 1649 sources that met 75 thresholds. These cited sources formed five distinct clusters with TLS = 337682. The most cited sources (journals) were as follows: Food hydrocolloids (TLS = 80437), Food chemistry (TLS = 44964), Journal of agricultural and food chemistry (TLS = 39230), Carbohydrate polymers (TLS = 28105), Langmuir (TLS = 27140), and Journal of food engineering (TLS = 24159)."

Authorship and Author co-citation analysis

A total of 603 authors have contributed to focused research on stability of functional beverages. Of particular note, Mcclements, D.J. was the utmost productive author with 7 articles (1066 citations) followed by Gao, Y. (7 articles; 289 citations). Visualization of co-authorship, based on a threshold of 20 citations each author, an author co-citation analysis was performed, which generated a total of 97 authors. These 97 cited authors clustered together

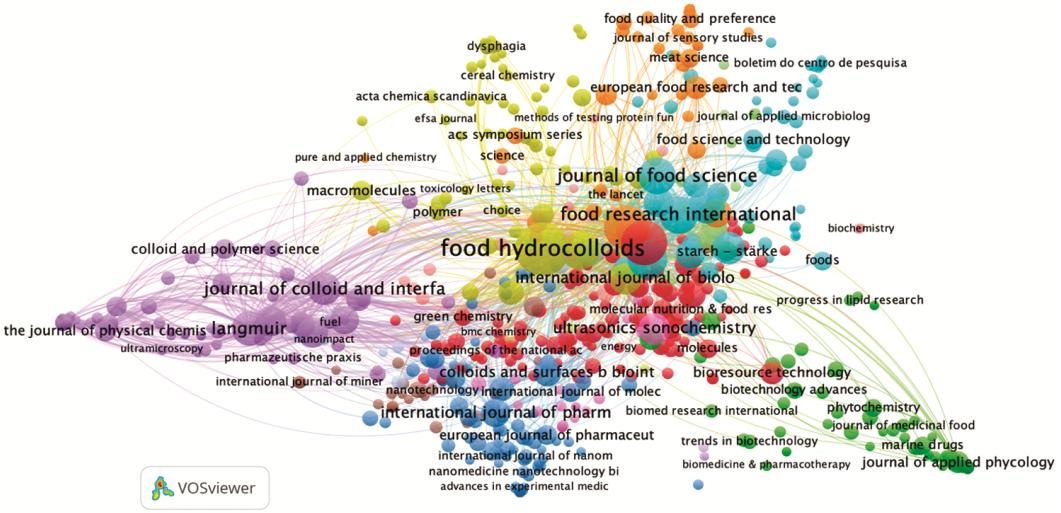

Fig. 3 — Co-citation of 1649 cited sources based on Total Link Strength (TLS)

in five distinct groups (TLS = 100780). In count, our results revealed that Mcclements, D.J. had the highest TLS score (20088), trailed by Dickinson, E. (TLS = 5484), Decker, E. (TLS = 5073), Weiss, J. (TLS = 4046) and Bai, L. (TLS = 3939) (Figure 4).

"Co-citation analysis and cited reference"

The "analysis of co-citation between cited references, a threshold of five for the number of citations was applied and obtained a result of 134 cited references, which formed four clusters (TLS = 5957) in Figure 5. "The top cited reference was "Dickinson, E. (2003). Hydrocolloids at interfaces and the influence on the properties of dispersed systems. *Food Hydrocolloids*, *17*(1), 25–39." (Citations = 20; TLS = 248), followed by "Chanamai, R., & Mcclements, D. (2001). Depletion Flocculation of Beverage Emulsions by Gum Arabic and Modified Starch. *Journal of Food Science*, *66*, 457–463." (Citations = 15; TLS = 186), "Kubo, M. T. K., Augusto, P. E. D., & Cristianini, M. (2013). Effect of high-pressure homogenization (HPH) on the physical stability of tomato juice. *Food Research International*, *51*(1), 170–179." (Citations = 14; TLS = 145), "Taherian, A., Fustier, P., & Ramaswamy, H. (2007). Effect of added weighting agent and xanthan gum on stability and rheological properties of beverage cloud emulsions formulated using modified starch. *Journal of Food Process Engineering*, *30*, 204–224." (Citations = 14; TLS = 146), and "Genovese, D. B., & Lozano, J. E. (2001). The effect of hydrocolloids on the stability and viscosity of cloudy apple juices. *Food Hydrocolloids*, *15*(1), 1–7." (Citations = 13; TLS = 61).

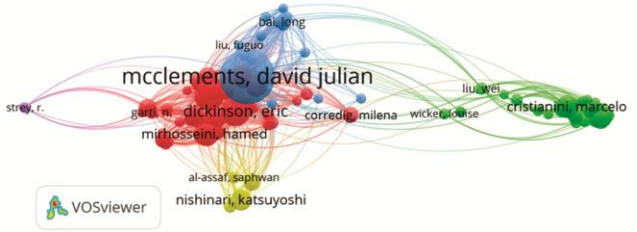

Fig. 4 — "Co-authorship network of the most influential authors, based on Total Link Strength (TLS) between authors"

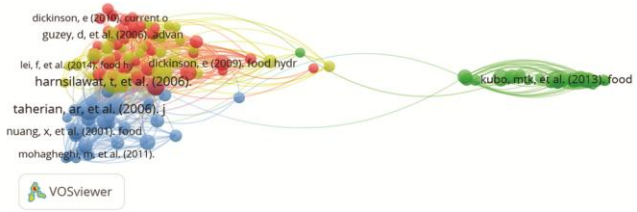

Fig. 5 — "Co-citation analysis of 134 cited reference based on Total Link Strength (TLS)"

Keywords analysis

The co-occurrence of keywords that appeared extensively in articles about the incorporation of stabilizers in functional beverages is illustrated in Figure 6. The delineation of keywords and the identification of their research hotspots relative to other disciplines depend on the analysis of keywords. "According to (Torres *et al*., 2021) using keyword analysis, researchers may investigate and emphasise the most prevalent study topics and concepts. Using the VO S viewer software, 650 words were identified from the downloaded documents and on using a threshold of three (*i.e*., at least three times the keywords get repeated across the searched articles, 60 keywords met the

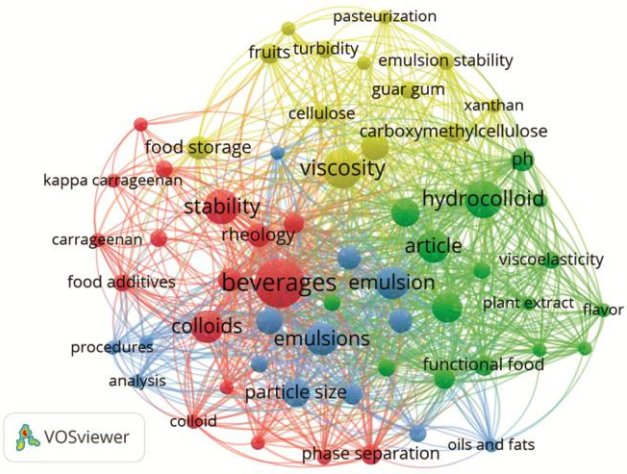

Fig. 6 — Co-occurrence of keywords

criterion. Keywords with stronger links to each other included beverages, hydrocolloids, viscosity, emulsions, gum arabic, colloid and particle size evident from the size of their circles. The observations corresponded to their Total Link Strength (TLS) of 119, 114, 111, 110, 98, 74, 73 and 72 in respective order. The colors of the various keywords corresponded to their research themes and categories as classified by the databases."

Conclusion

Towards the greatest extent of our expertise, the present work is the original bibliometric analysis intended towards classifying trends in worldwide research activities affecting stabilization of beverages by means of hydrocolloids. The study of application of hydrocolloids to solve the issues faced by the beverage industry through an analysis of research advancement with the field has revealed a broad-spectrum cumulative trend in recent years, particularly in areas of food hydrocolloids, food chemistry and food engineering. Assumed the importance of assessment of the current research activities with regards to usage of hydrocolloids to prevent destabilization in beverages, therefore there is a critical need to improve the quality and quantity of research activity in additional locations across the globe in order to address the challenges faced by the beverages industry through an analysis of research development in the field.

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Institutional review board statement

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Disclosure statement

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