



Review article

Thermal and non-thermal pasteurization of citrus fruits: A bibliometrics analysis

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ABSTRACT

Thermal and non-thermal pasteurization (TNP) process of food is not new to food technology, disparities in the merits and demerits of the two pasteurizations necessitate their uses concurrently. Bibliometric analysis of the subject matter is expedient to analyses of database for published publications. Especially to provide times, state-of-the art innovations and prospects of the techniques. In addressing these lacunas, we utilized VOSview visualization to establish connections among crucial elements within a dataset of 495 research publications gathered from Web of Science. This approach facilitated the identification of links and collaboration networks among key factors in the research landscape. Analysis of publications indicate thermal pasteurization is an age long practices, while non-thermal pasteurization is gaining more acceptance. This study exposed ranking differences in scholar's collaboration, citations of scholars, impactful institution and most published countries. United State, China, United Kingdom have largest publications of research in TNP among the top 10 countries. Coupling network and Sankey illustration showed new area of research where new researchers and scholars can begin new phase of findings.

Fruits are low-cost and most times readily available foods with high nutritional contents of minerals, vitamins and fiber [1]. Respect to epidemiological studies, fact revealed that diet contain fruits and vegetables are attributed to low risk of a-lot of non-communicable diseases, like atherosclerosis, stroke, cancer, diabetes and arthritis, prone to occurrence in human at aging period [2]. Antioxidant content in fruits and phyto-constituents – chemical compounds that occur naturally in plants and responsible for color and other organoleptic properties can prohibit acute and chronic diseases, thus living a healthier life [3]. Plasma carotenoids and vitamin C of integrated level are associated with increased intake of fruits which ultimately reduce the possibility of diabetes, cardiovascular diseases, neurological disorders and cancer [4]. Fruit are popularly known for their refreshing flavor attributes and appealing color with pleasant taste [5]. Flavor and color were major attributes to determine the acceptability of fruits which are largely dependent of its aroma compounds. The properties of fruits and vegetables and their by-products are essential sources of extract of bioactive compounds in the production of nutraceuticals and functional foods [6]. These are foods that are produced industrially or naturally formed, when consumed with divers of diet effectually will positively affect health beyond basic nutrition (see Fig. 1).

The genus of *Citrus* L. belong to family of *Rutaceae* and sub-family of *Aurantioideae* according to botanical classification [7]. The

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well-known, widely consumed fruits within this genus are oranges, mandarins, tangerines, grapefruit, lime and lemons. Currently; among the most economically important cultivated crops in terms of areas of land and production values around the world, while; oranges being more than 50 % of total citrus produced and consumed each year [2]. Citrus fruit is known to have originated in the Himalayan area of south-western China northeastern India, and northern Burma in Asia, and now has been diffused in more than 140 countries of the world [4]. It is cultivated in tropical and subtropical parts of the world, being a function of its water requirement for fruiting, growth and other cultivation factors [8]. However; short harvesting period, storage and shelf life are usually attributed flaws of citrus and limited their availability, reduce the probability of the scintillating feelings from citrus inclusive of nutritional and functional attributes all year round. Since it picking and consumption is within few days, weeks to months [9].

Harvested citrus are most times freshly consumed, processing it to value added products are brilliant methods of improving its industrial and economical connection web. This enhance better storage system and prolong citrus shelf-life beyond thirty-days and up to a year, which is beneficial to transportation of citrus produce from their growing region or remote area to other part of the world [7]. Different products are obtained from citrus fruits when processed in industrial scale or laboratory scale such as juice, jam, marmalade, and puree. Citrus fruits has a great deal of polyphenolic flavonoids, mainly flavanones, including hesperidin, naringin, narirutin neohesperidin and physalis peruviana, together with the poly-methoxy flavones, tangerine and nobiletin [6]. According to Ref. [3] Citrus fruits are common foodstuffs for human health especially high in contents good in promoting health, phytochemical and nutritional substances, such as multivitamins, pectin, carotenoids, fatty acids, limonoid glycosides and especially polyphenols in adequate concentration. In recent time; curative compounds blend with pharmacological effect have been identified in citrus fruits and their by-products. Phytochemicals that are valuable oils are now extracted from citrus peels, it contains high free radical scavenging and anti-fungal activity. Extraction processes on citrus are mostly done using steam-distillation, while; extracts from citrus fruit and fruit-seeds are used as sedative and cardiac tonic [10].

Pasteurization is a treatment used to terminate pathogenic microorganism in food, preformed to reduce or eliminate pathogens in low or high moisture foods [11]. Application of heat in pasteurization technology to low moisture food are classified into two: conventional thermal processes and energy-based technologies. Conventional thermal process involves direct heating from a heat source to the molecules of food constituents. System of heat regulation is of High Temperature Low Retention Time (HTLRT) examples are: baking, extrusion, roasting, frying and condensation steam processes. Energy based technology heat discharge differs from (HTLRT) e. g., irradiation, radio frequency heating and cold atmospheric plasma [12]. High moisture food has high microbial activities as a result of easy of microbial multiplication which often cause spoilage and other form of food deterioration, the method exploited for microbial deactivation includes, but not limited to the following, thermal pasteurization, dielectric heating and microwaves [13]. Also; high pressure treatment of pasteurization applies 300–800 MPa between a time range of 5–8 min and ultraviolet-C treatment 200–280 nm [14]. Pasteurization is relatively serene thermal treatment of food, usually; temperature is below 100°C, some literature confirmed it to be between 61°C - 65°C and for heating period of 30 min, in another vein; pasteurization could be High-temperature Short-time Pasteurization (HSP) at temperature of 72°C in 15 s [15]. The objective is to destroy vegetative cells of pathogenic along with nonpathogenic microorganisms. Occasionally; pasteurization is amalgamated with another preservation process namely acidity, low water activity and low temperature storage. Pasteurization is necessary though it may alternate the composition of food such as vitamins and amino acids. According to Ref. [16] growth in children at infant level that are taking pasteurized milk are lower compared to growth received by those consuming unpasteurized milk. Pasteurization can change activity and concentration of several biological factors and antioxidant. Today's technological advancement identified that several pasteurization methods influence antioxidant content and properties in foods [14].

Thermal processing of foods is the most widely technology and one of the earliest methods of food preservation [12,17,18]. Application of heat on food is to transform nature and structure of food through the processes of pasteurization, sterilization, cooking and baking. Classification of all these processes depend on temperature degree and level of reformation in food structure [11,14]. Thermal pasteurization is highly peculiar to citrus fruits, two out of three mode of heat transfer are applicable to pasteurization of

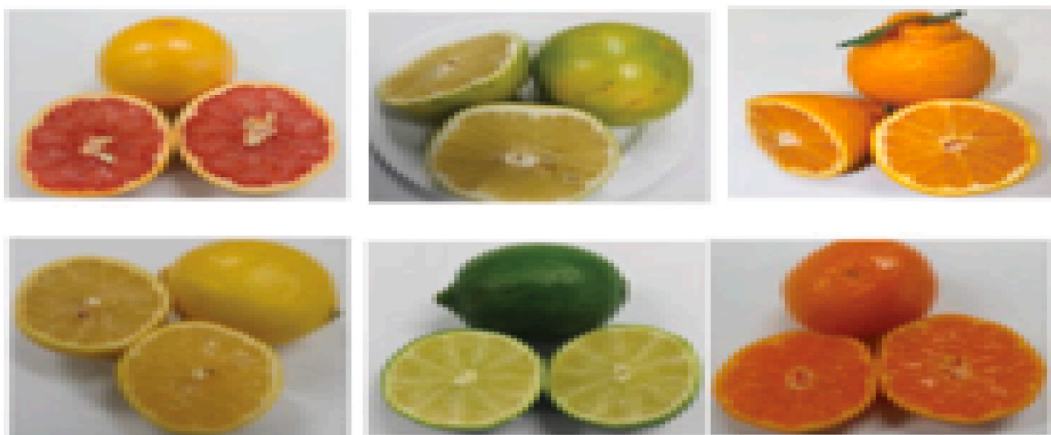


Fig. 1. Collection of some citrus fruit.

high-moisture fruits-citrus, conduction and convection [19]. Development in technology of thermal pasteurization has followed a trajectory originated from conventional or traditional thermal process to another generation of microwave heating with improved level of precision, processing time and quality of output [5]. In addition; sensible heat is attained in the product using steam-controlled condensation which regulate moisture absorption to maintain drying saturated condition of steam [14]. Super-Heated Steam (SHS) heated beyond saturated steam at the same pressure are supplied to aid dry steam to attain much higher temperature being produced from electrical resistant heater [20]. Introduction of electromagnetic engineering in food processing gave raise to ohmic heating and infrared radiation in fruit pasteurization which has become a widely accepted form of processing in food industry [12,17]. Radio frequency (RF) was designed to overcome defect of inadequate depth of heating in microwave and reduce heating rate but at high temperature. It can swiftly change temperature of agricultural produce exponentially and more depth of heat penetration, positive and negative charges of the RF react with proton and neutron in molecules of foods [5,21,22]. The global acceptance of RF in food processing industry is a function of its potentials to reduce nutrient losses, reduced heating duration and increased scale of production.

Heat pasteurization of juice accompanied with microbial inactivation benefit still face challenges on the quality of products, texture, viscosity, color, flavor and appearance [23,24]. Demand by consumers on freshness and high quality of citrus juice coupled with government regulations on additives, inclusive of demerits from thermal treatment, necessitate an alternative method of pasteurization – non thermal pasteurization [2,17]. This technique includes pulse electric field (PEF) high pressure processing (HPP) high-pressure carbon dioxide (HPCD) ultrasound or sonication and ultraviolet application UV-C radiation, aims at eliminating microorganism and enzymes by changing their biological and chemical structure during short processing time [9,25]. Change process occurred within a temperature range of 40°C–55°C a palatable increase in temperature of citrus juice, reducing undesirable devaluation of chemical compounds, alternation in physical aspects and organoleptic properties of citrus fruits [26,27]. High pressure processing (HPP) innovation is applicable to thermal sensitive produce like citrus fruit juice for inactivating microorganism and enzymes without causing degradation to its components. Citrus is evenly subjected to pressures at almost room temperature, based on viscosity and other factors of citrus nature, increases of temperature by additional 3°C per 100mpa must be determined [28]. High-pressure carbon dioxide (HPCD) technology is utilized for cold pasteurization destroying microorganism and enzymes due to application of CO₂ below 50 mpa. Carbon (iv) oxide is easily accessed gas, non-harmful, nonflammable, and has no unacceptable defect on the quality of citrus fruit juice produced [27,29,30]. The dissolution of CO₂ in citrus will reduce the pH level temporarily until the pressure is removed or changed. Ultrasound is classified as vibrational energy, producing sound energy from electrical or mechanical sources [31,32]. Energy produced are low frequency and high power ultrasound between 20 and 100 kHz, 10–1000 wcm⁻¹. Inactivation of microorganism and enzymes was done through mechanical and chemical effect like mechanical cavitation and free radical formation [10]. UV- C is in the category of electromagnetic spectrum ranging from 100 to 400 nm, it is further sub-categories into three, UV-A ranged from 320 to 400 nm UV-B between 280 and 320 nm UV-C at intervals of 200–280 nm [33]. Application of UV- C in water and fruit juice processing was strongly recommended, significantly on its light absorbing effect to destroy mode of microbial DNA or RNA in microorganism.

Decades ago; majorly after WW II state of different nations in EU and America was under pressures to curb disease outbreak, several research, investigation and health findings confirmed most of these diseases were caused by quality of food consumed. In this era government regulation on food industries backed by act of law with enforcement, reform the food industry and bring scholars and researchers for probabilistic futuristic development of the food industry [34]. Tense in hundreds of scholars have done excellently in citrus fruit juice research, for instance Ref. [35] reviewed and presented the perspective of Thermal and Non-thermal Pasteurization (TNP). A decadal analysis has provided enough reference and keywords of a large and comprehensive detailed of TNP all over the globe. Cano and Hernández in their intensive literature review [36] postulate the need for optimization of processes of TNP of citrus. Human factors, machine factors, plant and climatic factors that can affect TNP was critically reviewed by Ref. [37]. Recent development in food technology, focus in liquid foods was covered [38] few of project and research were published in liquid food processing using bibliometrix analysis from the research field.

In order to compile, organize, understand and utilized several previous findings in a particular research rivulet, scholars employed series of quantitative and qualitative reviewing method. A noteworthy among these is bibliometrix; its potential objectives is to be able to bring forth a reproducible, transparent and systematic review mechanism on the premise of a statistical evaluation of science, domicile in web of science, Scopus, and dimensions [39,40]. In contrast to other forms, bibliometrix encompass peculiar features and precision in authentication of analysis. Complex data handling, development of notion, with good structural computation of wide range data information, indicating trends of connection in period, research themes, institutions, organizations and countries are all but not limited to these features. Furthermore; Identifying the scope of research area, adding contribution to knowledge and pointing out top-efficient research, scholars and institutions [41]. [42] present a bibliometrics analysis on food regulation and management to enhance safety of consumption, they were able to identify links versatility and relevancy of articles, institutions and countries. Bibliometrics analysis and scientometric review has been carried out by Ref. [43] on the need of characterization and solution to challenges on ohmic heat treatment in food industry. Interest and performance of authors in food research were vehemently stated in analysis of result, indicating areas new research can be carried out. Citrus fruit juice is one of the areas that has little in articles and institutional performance relative to authors and countries [44]. However; some bibliometric reviews have been done on pasteurization, but; bibliometric analysis on heating effect on thermal sensitive citrus fruit compounds and development for novel non-heating techniques has not been explore to a larger percentage [45]. Handling of citrus fruits to form beverage or juice requires technical precision in its processing chain. Temperature applied during processes determine the quality of juice, non-heating system is more preferable due to its advantage over heating system, but; this doesn't come without challenges of procurement and scaling in production. Hence; it expedient to provide a systematic review of bibliometrics-based to look inwards on scholars, articles and organization impact in thermal and non-thermal pasteurization (TNP) of citrus fruits. Procedure to carry out this bibliometrics study,

fundamentally query these four following aspects.

- a) What is the silhouette of the bibliometric analysis evaluation of TNP?
- b) How the cooperation networks of TNP research can be established?
- c) How is the thematic trend of the growth in TNP?
- d) What are challenges TNP growth is facing and how to fathom them?

In response to tetrad sections of concern to academic research highlighted above, we use co-citation, bibliographic coupling and cluster analysis evaluation approaches to appraise the developmental drift of TNP research. VOSviewer was used to frame the profile of research on TNP. The objectives of this research is aimed at analyzing publication trends over time to discern growth rates and patterns in research output on thermal and non-thermal pasteurization of citrus fruits, concurrently; identifying gaps in the existing literatures to guide future research opportunities and exploration.

1. Methodology and extraction sources of the data

1.1. Methodology

Scientific review of publications involves use of scholarly structured literature review methods, numerous merits are intertwined with this methods base on the fact that scholars and authors have used them to conduct comprehensive analysis for publication [39, 41]. Its processes allow tens of thousands of published scientific findings; especially, visualization function permit authors to obviously understand the publication drift. The challenge facing these methods is limited to the integral multiple increase in time spent by an author relative to exponential increase in number of studies [46]. Bibliometric analysis has been successfully used in different field, for instance; identifying trends of engineering development in food processing, effects of some bioactive compound in human calls, investigating zero energy use, landscaping, social sciences, law jurisprudent's implementations and much more. Consequently, in this study, thermal and non-thermal pasteurization of citrus fruit juice studies was performed using the following triad methods: co-citation, bibliographic and cluster method.

➔ **The co-citation method:** it was first used in the United State of America by an intellect in science named Henry Small in 1973 [39,47] Two published article were co-cited with both being cited in the third article, consequently; co-citation link of dyad articles were acknowledged in the third article [46].

The bibliographic coupling method: this conception was advanced firstly in 1963 by Kessler [47]. The occurrence of duo studies having a third document in their reference, established a relationship between documents known as coupling.

The cluster method: Clustering is the categorization of subset into various groups characterized by their degree of relativeness. Subset formed are called clusters, which will be of various number, three, four, five etc. [48]. The formation of cluster is based on the level of similarity, those with higher similarity fall into a cluster while those of lower similarity fall in another cluster.

1.2. Data sources and data processing

The data used for analysis were sourced from a query in Web of Science database between 1999 and 2022, the utilization of this timeframe and VOSviewer dependent factors, including threshold settings, will yield comprehensive results aligned with the objectives of the subject matter. There are several academic resources data base available online, among them few have been arguably ranked top over others, Google Scholar, Web of Science and Scopus are the worlds most recognized. We restrict our search to relevant studies on Thermal and Non-thermal Pasteurization (TNP) of citrus fruit in the discipline of food processing. Web of Science is an online platform which contains millions of research items, owned by Clarivate, functions under Institute for Scientific Information, Philadelphia, United States of America. Recognized has the largest academic online source of highly detailed journals with iconic impact factor, though; it is subscription-based scientific citation indexing service (SCIS). Researcher can conduct an intensive citation search inserting group of key words or single journal details or large number of journals, in some instance both keywords and journals could be used. The opportunity of In-depth exploration of specialized research areas with an academic discipline has been emboldened. An evaluation and selection process base on recency, relevancy and impact of journal and whether or not papers are peer reviewed, determines the acceptability for indexing in Web of Science [47]. Scholars can stipulate their search desire on Web of Science using Boolean logic to include or expunge search terms and specify journals. We specified "Thermal" OR "Non-thermal" AND Pasteurization OR Impact AND Physicochemical AND Properties AND Bioactive OR Compounds AND Citrus AND Foods as our key words being used largely in the area of study.

2. Data analysis

2.1. Discussion

In the course of this study, the tool used to produce the visualization of links, trend and relationship between authors, sources, organization, documents and countries, using major analysis of four types, co-authorship, citation, co-occurrence and co-citations, for the analysis of TNP of citrus fruits was VOSviewer.exe 1.6.18 (2010) by Nees Jan van Eck and Ludo Waltman, Leiden University,

Leiden, Netherlands. It is a software designed fundamentally for visualization, its performance in bibliometrics analysis has been recommended by scholar.

The table above presented top ten most cited papers in relation to thermal and non-thermal pasteurization discussing citrus fruit reactions and improvement. Also; further areas of exploration of citrus fruit juice development published in food journals were extracted from web of science data base. Most cited article that top the list is a paper by Ref. [49] published in Food Research International. We identify two outstanding journals among these ten, whom appeared twice on different articles, Food Research International and Journal of Food Science. This indicate that till recent time being the most impactful journals in this specific field. Distinction between them can be evaluated in their impact factors and some other scholarly academic factors applicable to journals [46], have similar views in journal evaluation disparities. While at same instance; arguments around these topics are occurring across diverse sub-discipline of food pasteurization and processing (see Fig. 2).

Evaluation of authors in VOSview analysis using evaluation item of co-authorship and sub unit authors was carried out. We set our analysis functions to be 25 maximum numbers of authors in a document, minimum number of two document from an author, coupled with minimum number of two citations of an author. Total number of authors that meet the thresholds were 114 in which only 40 were visualized for graphical representation. Aguilar Balagurusamy and Chavez-monica are the most productive authors in this field having publish 25 articles each, they were seconded by Aadil, with 10 articles, Aguilar Cristóbal and Roobab were ranked third with 7 articles each. Numbers of articles by a scholar is a prerequisite for total link strength between clusters. The cluster with highest strength is where most productive authors were found with 73 link strengths as shown in Fig. 3b. The map showed in Fig. 3a has network that is quite spread out with the largest cluster, housing the three most prolific scholars aforementioned in this research area. This result indicates that new entrance to field have wide space for exploration to join any exiting node of researchers or perhaps conduct their own research creating another node of research interest [50]. in their review on food safety using bibliometric methodology made similar report on co-authorship analysis.

The quantity of citation from an institution predicts relevance and impacts of research being published from the university. In this ranking, University of Florida UF has the highest citation in (TNP) of fruit articles. It was observed that University College Dublin (UCD) came second with 744 citations while Nanjing Agricultural University (NAU) is found at the twentieth position of the ranking. Majorly; institutions from United State of America (USA) and China are leading in the statistical result with numbers of occurrence in their institutions shown Table 2, hence; China Agricultural University (CAU) and Washington State University (WSU) also made the list

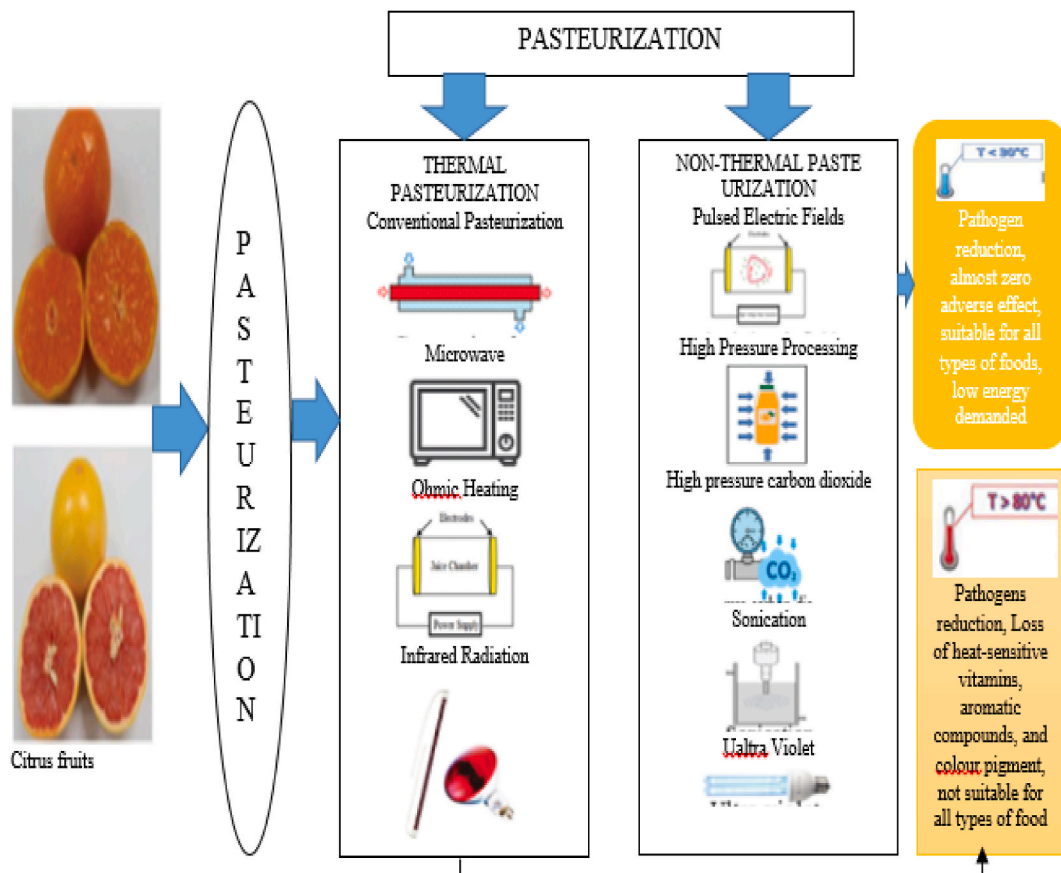


Fig. 2. Types and techniques of pasteurization.

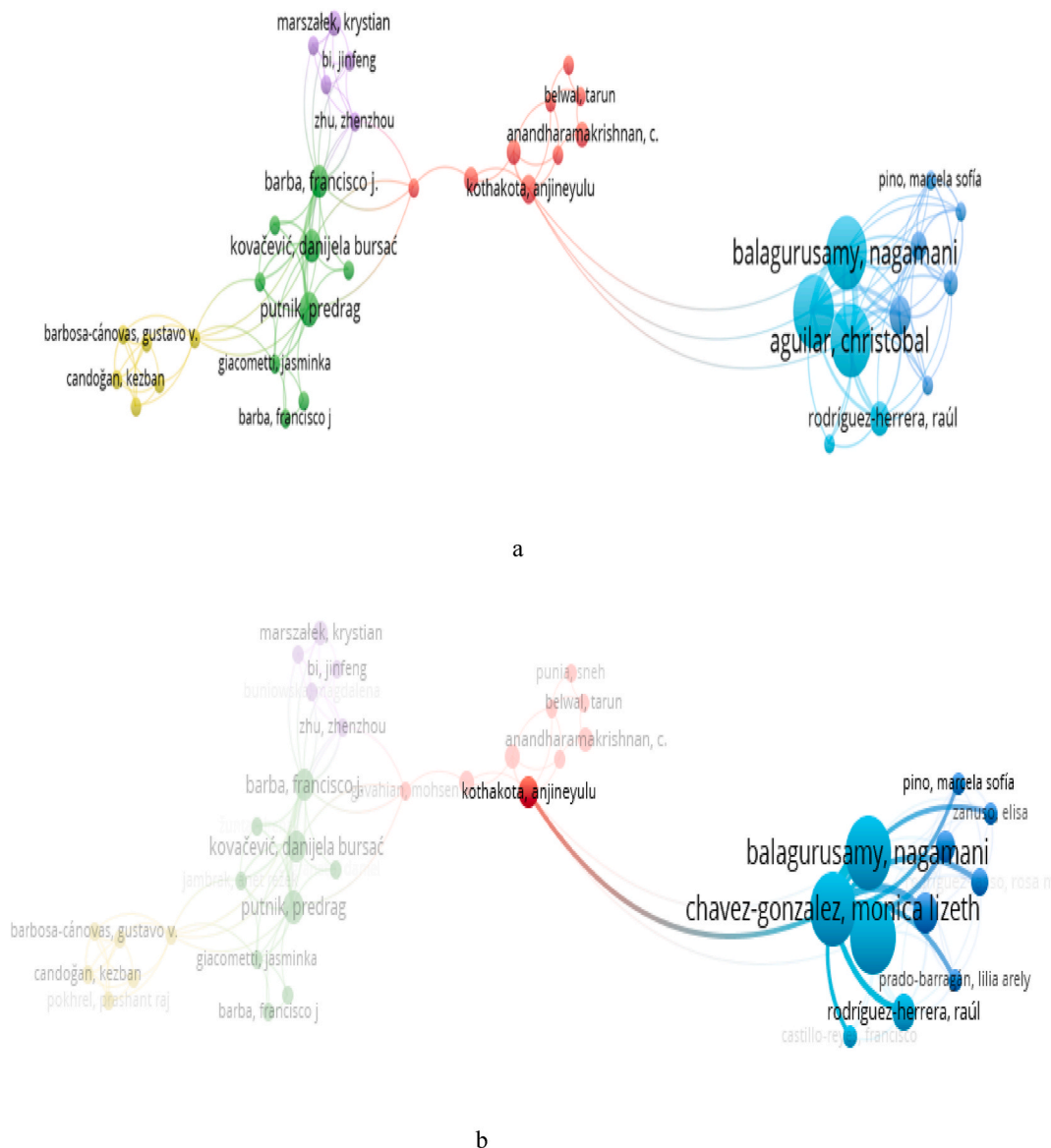


Fig. 3. a: co-authorship map by authors with wide spread links, b: co-authorship map by authors showing specific links.

both are in China and (USA) respectively. The details of all the top twenty institution are listed in Table 2 inclusive of their ranking and citations.

Comprehensive research work warrants scholarly inclusion of interdisciplinary involvement of researcher. Research in different field should not be exclusive to scholars and ideas in other related areas [37]. Scholars have postulate essentials of joint research work which is not limited to research area, departments, institutions or counties, but to the general world. In resent many research work were conducted with collaboration with scholars in other countries of the world [51]. Evaluation of international collaboration in TNP of citrus fruits was analysis to identify countries cooperating to publish TNP – related topics in food processing. Scholars from 59 countries have published articles in the view area of interest. Our threshold prerequisites were minimum of four document and one citation from each country. However; only 32 countries meet the threshold. Fig. 4 presented map of clusters indicating strong bond between countries researching in TNP of citrus fruits, seven countries form large web centralized USA and China.in the second largest cluster of six countries, United Kingdom (UK) and India form strong link of collaboration. Scholars in China and USA have collaboration with research in other countries of the world on this map, as well; have published the most related TNP articles in citrus fruit processing, both have published 73 and 72 paper respectively. Vehemently; China is slightly leading this district closely followed by USA, while; India, Spain, United Kingdom and Germany were not far in irregular distance intervals away from the two giants in this research spectral with publications numbered 55, 26, 24 and 21 respectively. 52 [52] made consonance remark on milk preservation placing all these developed countries in high ranked positions in the food industry.

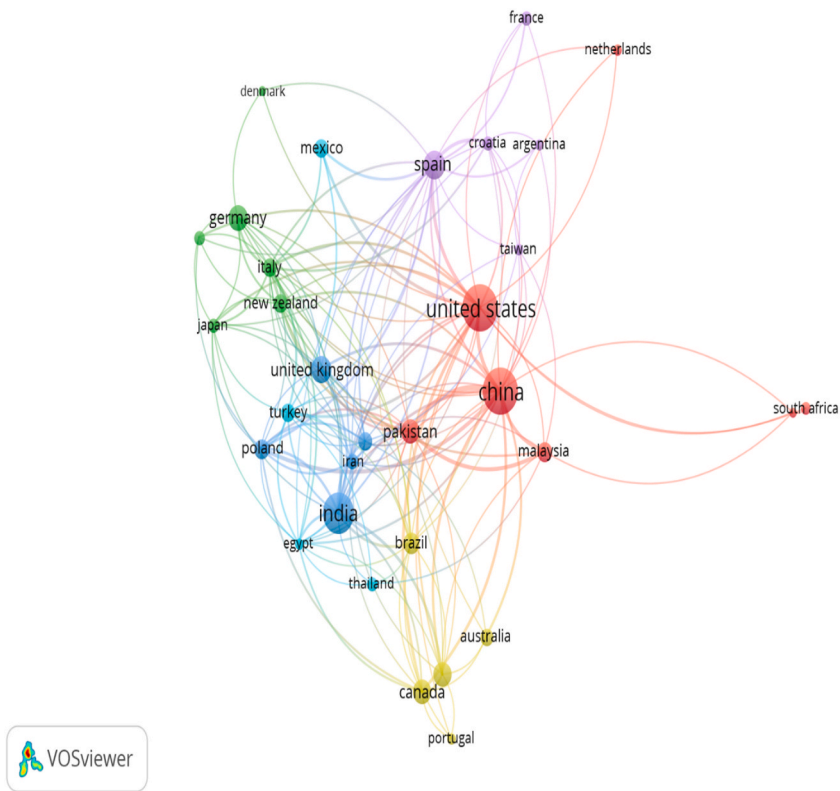


Fig. 4. Co-authorship map by countries.

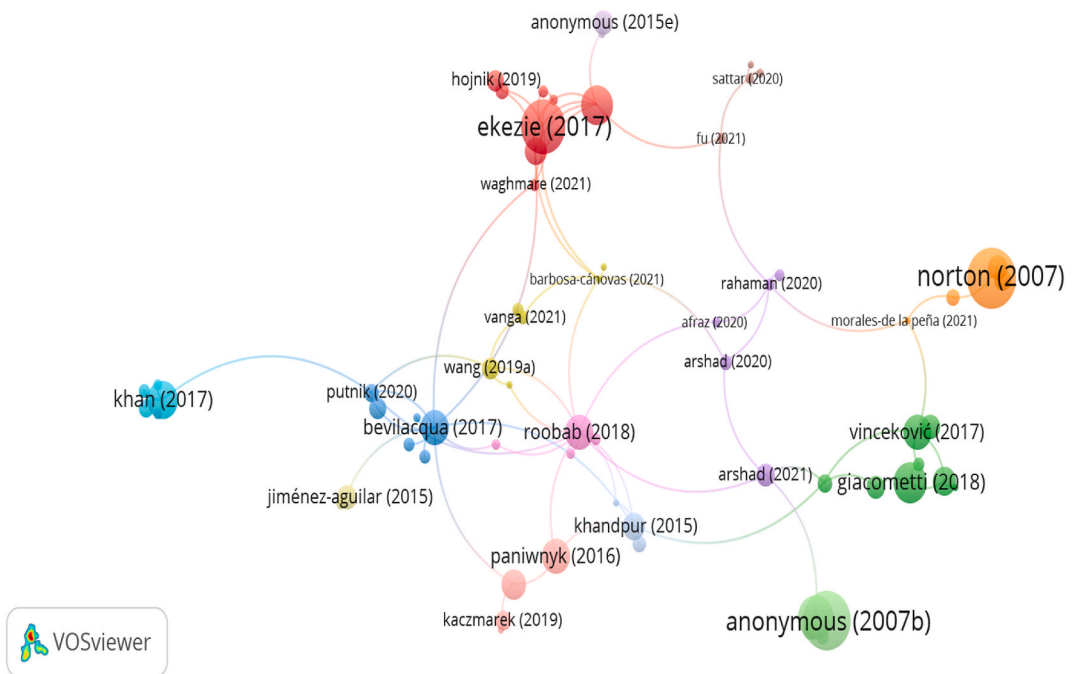


Fig. 5. Citation map by documents.

2.2. Citation analysis

Potentials of VOSview analysis enhance measures of numbers of times two subjects (paper, authors, journals, institution, and countries) cite each other to identify the strength of links among the subjects. Fig. 5 shows a web map analysis of papers, indicating connections in clusters which is moderately enough and areas of easy access will still allow further selection of new areas of interest and new innovation in the technology of TNP of citrus fruits in food processing journals. The analysis of relationship between journals was conducted, under premix of two articles from each journal and minimum of one citation, 28 paper were visualized in six clusters. The largest cluster of journals was led by Food Chemistry with the highest numbers of publications. This preriquities correspond with 53 [53] in the bibliometric analysis of food safety using artificial intelligence (AI). Food Chemistry is one of the most productive journals in this research section aforementioned in Table 1. Three out of six clusters have almost equal capacity in publication, predicting closeness in the range of their impact factor (IF) evaluation. Total link strength formed the basis of map in Fig. 6, though some journals have more article and citation but yet ranked below others. This could be a function of IF of the journal, similarly [54]; opined, impact factor is significant in the degree of citation and interest of authors, researchers, and writers to choose or not to choose an article for citation.

Much more; we consider links between different institutions within the captured area of our scope. Our stipulation was set for at least three publications from each university, 59 universities meet the threshold while 47 were captured for visualization of VOSview. Grouping of institutions into clusters was set to have minimum of four items in a group. Nine items form the largest cluster, South China University of Technology (SCUT) and University College Dublin (UCD) were strongly centrally connected in this cluster among top twenty in Table 2. University of Agriculture Faisalabad (UAF), University of Zagreb (UZ) and Indian Institute of Food Processing Technology (IIFPT) were leading in second, third and fourth clusters. Result analysis in Map format is presented in Fig. 7 indicating inclusion among organizations and probable research connection. International link among countries shows level of citation and collaboration in research. This was evaluated from the number of research publication from all concerned countries relative to subject matter. We set our cluster grouping to not less than four in a cluster in result data, four clusters were formed. Fig. 8 a map shows web of connections indicating prominence and productivity of countries. The largest network consists of nine members with United State leading, while; China made the follow-up in the second place with countries like Portugal, Japan, Poland etc. centered on it. Spain and India were found in third and fourth layer of ranking; but were in apex position in their various cocoon. Developing countries like Ghana, Nigeria, and Pakistan etc. have much more to explore in their local fruits that can bring new brands of citrus fruit juice to technology of TNP of fruits. If this is attained, they will be of much value as much as developed nations. Citation analysis revealed those papers, authors, journals, institutions and countries all are found to form clusters with wide range of existing opportunities for new researchers and prospective authors, whether to join existing research trend or to form new research area in Thermal and Non-thermal Pasteurization (TNP) of citrus fruits in the domain of food processing [55]. corroborate our observation relative to citation within countries and among countries.

2.3. Bibliographic coupling net work

Document analysis in bibliographic coupling network was in relative to authors of these papers inclusion of year of publication. Fig. 9 presented a graphical representation from the VOSview analysis, emphasis was made on the first five documents authored by *Bevilacqua (2017)* *Roobab (2018)* *Giacometti (2018)* *Kovačević (2018)* *Paniwnyk (2016)*. On the basics of their total links strength

Table 1

Top ten most cited articles relative to thermal and non-thermal processing of fruits in food journals.

S/ N	Year	Title	Journal	Author	Citations
1	2015	New opportunities and prospect of high-pressure treatment to improve health and safety attributes of foods. A review	Food Research International	Barba, Francisco et al.	264
2	2010	Design of nano-laminated coatings to control bioavailability of lipophilic food components	Journal of Food Science	Mcclements, david Julian et al.	207
3	2011	Effect of thermo-sonication on bioactive compounds in watermelon juice	Food Research International	Cullen et al.	204
4	2008	Phenolic acids, flavonoids, vitamin C and antioxidant capacity of strawberry juices processed by high-intensity pulsed electric fields or heat treatments	European Food Research and Technology	Martín-belloso, Olga et al.	202
5	2017	Emerging techniques for assisting and accelerating food freezing processes: A review of recent research progresses	Critical reviews in food science and nutrition	Sun Da-wen et al.	191
6	2011	Microencapsulation of bayberry polyphenols by ethyl cellulose: Preparation and characterization	Journal of Food Engineering	Zhang Min et al.	138
7	2013	Effects of ultrasound treatments on quality of grapefruit juice	Food Chemistry	Aadil, Rana Muhammad et al.	137
8	2000	Modeling conductive heat transfer and process uniformity during batch high-pressure processing of foods	Biotechnology Progress	Van loey, Ann et al.	128
9	2007	Effects of pulsed electric field treatment of apple mash on juice yield and quality attributes of apple juices	Innovative Food Science and Emerging Technologies	Knorr, Dietrich et al.	126
10	2003	Mild-heat and high-pressure inactivation of carrot pectin methylesterase: a kinetic study	Journal of Food Science	Hendrickx, Marc et al.	126

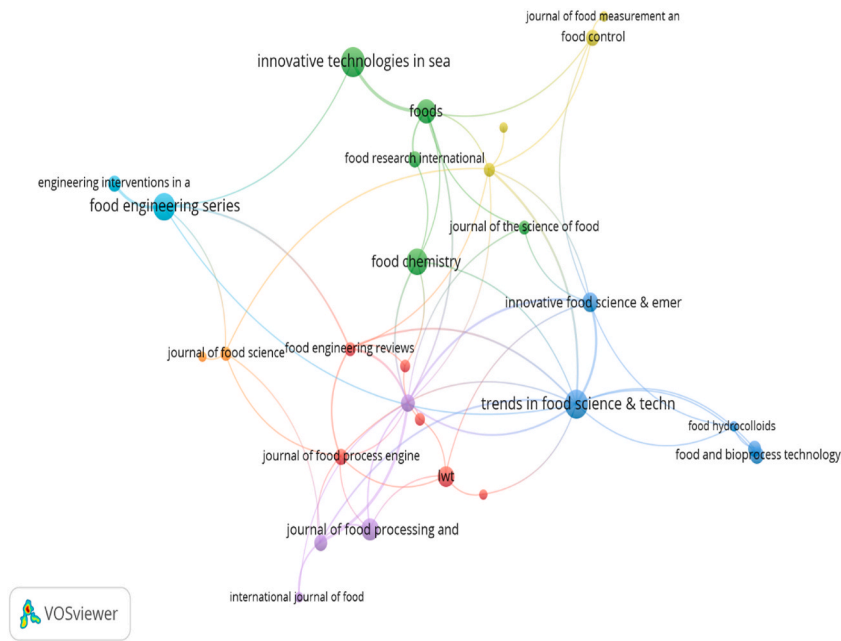


Fig. 6. Citation map by journals.

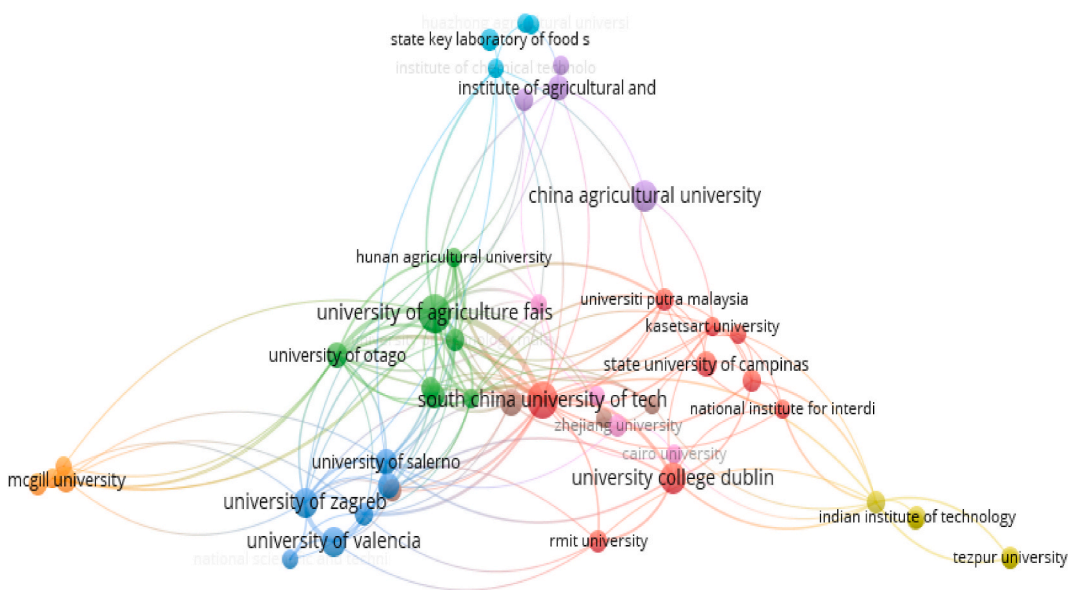


Fig. 7. Citation map by institution.

Bevilacqua 2017 came first with highest impact of productivity, while on the basics of citation Giacometti 2018 was the most valuable. Normally; one will think citation rate should create more links but it is otherwise, dependent of network connection references which gives the link strength. The error bars on the graph is proportional to the size of data available for the statistical analysis of the factor and variables. This indicate the amount of error in the data set was infinitesimally small and negligible. We set prerequisite on VOSview to minimum of 60 citations from each documents 69 articles met the threshold, 39 were captured on the map while five are most productive. The implications of these indications is that research in the field Thermal and Non-thermal Pasteurization of citrus fruits TNP still has several areas of exploration and could still be well research on for further findings.

Analysis of result on sources coupling in Fig. 9 indicate that Journal of Trends in Food Science and Technology has the largest weight in food thermal and non-thermal pasteurization, seconded by Journal of Comprehensive Reviews in Food Science and Food Safety, Journal of Foods, Ultrasonic Sono-chemistry, Food Chemistry was found in the third, fourth and fifth positions respectively.

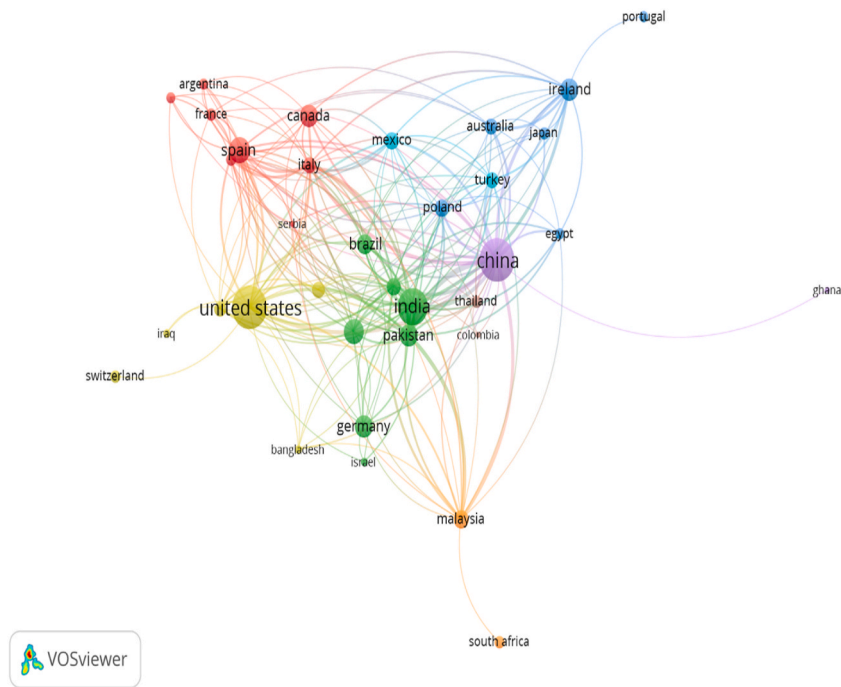


Fig. 8. Citation map by country.

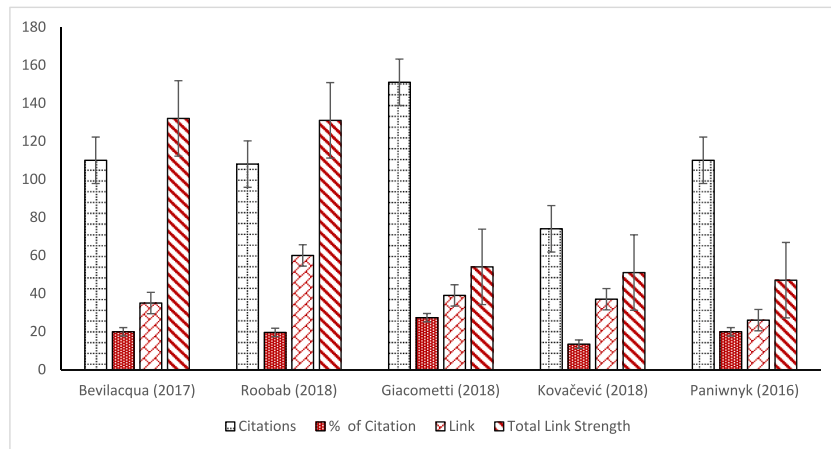


Fig. 9. Network of document bibliographic coupling.

Table 2

Top twenty institutions in co-authorship analysis.

Rank	Institutions	Citations	Rank	Institutions	Citations
1	University of Florida	804	11	China Agricultural University	226
2	University College Dublin	744	12	University of Otago	186
3	South China University of Technology	502	13	Technological University Dublin	181
4	University of Zagreb	462	14	Monterrey Institute of Technology and Higher Education	177
5	University of Valencia	404	15	Washington State University	162
6	University of Salerno	369	16	Kunming University of Science and Technology	128
7	Mcgill University	263	17	Institute of Chemical Technology	110
8	University of Agriculture Faisalabad	255	18	University of Technology Malaysia	99
9	Cairo University	232	19	Zhejiang University	90
10	Indian Institute of Food Processing Technology	227	20	Nanjing Agricultural University	84

Weight of each journal intensify its relevancy and connectivity, all mentioned above weigh 637, 618, 405, 352 and 335 in resonance with their total share value of 13.87 %, 13.46 %, 8.82 %, 7.66 % and 7.29 % which is their percentage contribution to link strength. Journal of Trends in Food Science and Technology, Journal of Comprehensive Reviews in Food Science and Food Safety and Journal of Foods were two most impactful in the field of subject matter, being centered by others with strong links between them based on the citations connection. Coupling of published papers exhibits the correspondence between dyad papers that were cited [56]. In their research on strawberry pasteurization postulated importance in the relationship of weight strength in links and percentage contribution in evaluation of authors, journals and publications on their impact to human development for global recognition.

Analysis of authors in bibliographic coupling network in Table 3 presented top ten authors ranked on the basis of their total link strength. The requirement for the threshold was set to at least four documents from an author, 21 authors meet the requirement, but 10 of them were most significant. Five clusters were formed, authors with least weight of total link strength were found in cluster one, though; of moderate links. Putnik, Predrag and Kovačević, Danijela Bursać in cluster two, were the best two authors. Basically; positions in clusters depends on individual links, members in same cluster have close value of links. The highest weight was 1320 earned by Putnik, Predrag while the least of the top ten was 49 earned by Kovačević, Danijela Bursać. Wide range of weight strength between the first and the tenth position indicate unexplored areas of research in Thermal and Non-thermal pasteurization of fruits. Largely; developing countries have low representation among the authors, predicting much work to be done on local fruits in their geographical area.

Institutions that were actively involved in research of TNP of citrus fruits data were analyzed, Fig. 10 shows a map of web connections among institutions based on the strength of their citation links. University of Agriculture Faisalabad (UAF) made the lead with twelve articles, weight of 5179 and percentage share in weight strength of 10.12 %. Its connection with South China University of Technology (SUCT) has no equal, making (SUCT) the second most productive in the same cluster with UAF. The third, fourth, and fifth positions were occupied by University of Salerno (US) with weight 2950, University of Zagreb (UZ) of weight 2622 and Washington State University (WSU) of weight 2289, corresponding to their percentage share weight contributed by each of the remaining four of top five members, 8.86 %, 5.76 %, 5.12 %, 4.47 % respectively. In addition from this result emphasis on the connection and continuation of research work in every institution relative to other institutions in the same cluster. This was also observed by Ref. [57] in the bibliometric review on food chain. Percentage weight of contribution from each journal may generate more drift of publication which will increase their impact factor (IF). Bibliographic analysis of countries coupling was conducted, its map in Fig. 9 showed the total weight of 153312. We set our condition of analysis to minimum of 3 documents from each country, at least 2 citations, only 41 countries were able to meet the threshold. Five clusters were formed from, each cluster was centered round a particular country, predicting the relativeness in research citations and referencing. China is the most productive country shown on the map by the size of its node followed by United States, India, Italy and Spain, these are the countries that make the top five productive countries. Though; USA and Spain were in same cluster, showing closeness in their pattern of research in fruit juice pasteurization. In recent times, most citations from developing countries were found among developed countries indicating collaboration in the pattern of their research and further development in research of TNP of citrus fruits juice (see Fig. 11).

In the analysis of co-citation of references, our benchmark was minimum of ten citations for any document to meet the threshold. VOSviewer numerical qualitative analysis extract 31 items for mapping, showing citation link strength, Fig. 12 percent map of connections between journals and publication. Publication of Wang et al. (2012) published on *The European Physical Journal* was at top of list with percentage share weight contribution of 7.54 %, seconded by paper of Bermúdez-aguirre et al. (2013) published on *Journal of Food Control* with 6.51 % of weight contribution. Misra et al. made very good impact, their publications in 2011 and 2014 were in third and fourth position, published in *Journal of Food Engineering Reviews* and *Journal of Food Engineering*. The last of the top five authors and journals is Niemira et al. (2008) in *Journal of Food Protection*. Co-cited sources revealed relationship between journal house and publications. Journals that have published most cited papers were ranked in order of their citation weight and link strength. In Fig. 13 it was obvious that *Journal of Food Chemistry* published most cited journals related to Thermal and Non-thermal Pasteurization (TNP) of citrus fruit juice, with citation weight of 195574. Among the top ten journals, *International Journal of Food Microbiology* has weight of 55717 but was placed at the tenth position. Sources that were found between second and ninth positions were *Journal of Food Engineering*, *Journal of Agricultural and Food Chemistry*, *Journal of Food Science*, *International Journal of Food Science and Emerging Technologies*, *Food Research International*, *Trends in Food Science and Technology* and *Food Control*. Future publications in relative to TNP may be channel to these journals due to the index, IF, SSCI. Journals that are said to have low rating will up their benchmarks for acceptance of publications related to food processing. 58 [58] made a similar recommendation in analysis of dairy food thermal processes using bibliometric methodology.

Analysis of cited authors was conducted, our condition stipulated was minimum of 72 citations and 35 authors meet the threshold. Map in Fig. 14 shows four clusters formed in the VOSviewer analysis, all have good linkage with one another. In this analysis top five authors were majorly emphasis on, though 35 of them have made impact in food processing. Barba, Francisco has the highest weight of 9648 and his node on the map has the boldest colour, placing significance on his contribution in fruit pasteurization. He was rounded in same cluster by Vorobiev Eugène, Grimi Nabil, Putnik Predrag, etc, these are authors that work in similar research area with him and cited some of his research work. Martín-belloso Olga, is the most cited author in the second cluster, While Cullen Knor, Dietrich, and Aadil Rana Muhammad were in third, fourth and fifth positions. New researcher interested in further research in thermal and non-thermal pasteurization of citrus fruit juice may join link with any of the 39 authors that have profoundly made significant impact.

Most countries of the world have made significant contribution on the research of foods, pasteurization of fruits in particular. In this topic, countries like China, United States, India, United Kingdom and Germany have made landmark records, establishment of governing body, research institutions and developing plans that can stand the test of time in the food sector. In Fig. 15, our visualization of three fields, consist of three main element of journals, keywords, countries with the flow of links between them using Sankey diagram. This represent the trends of connection between nodes of actions and flow of development between the nodes. Significantly; the

Table 3
top 10 authors relative to bibliographic coupling network.

S/N	B1	B2	B3	B4	B5	K1	K2	K3	C
1	Putnik, Predrag	6	431	71.8333	19.55	1320	18.31	7	2
2	Kovačević, Danijela Bursać	5	280	56	12.69	1219	16.91	7	2
3	Aadil, Rana Muhammad	10	246	24.6	11.15	1209	16.77	9	5
4	Roobab, Ume	7	235	33.57	10.65	1193	16.55	9	5
5	Barba, Francisco j.	5	248	49.60	11.24	1042	14.45	7	2
6	Srivastav, Prem Prakash	5	22	4.4	0.997	519	7.20	6	3
7	Verma, Deepak Kumar	4	22	5.5	0.997	517	7.17	5	3
8	Sun, Dawen	4	695	173.75	31.51	91	1.26	9	4
9	Aguilar, Christobal	25	13	0.52	0.589	49	0.67	8	1
10	Balagurusamy, Nagamani	25	13	0.52	0.589	49	0.67	8	1

Note: B1 is the {Author} B2 Number of {Documents} B3 is weight of {Citation}, B4 is score {Avg citation}, B5 percentage share weight of {citation}, K1 is weight of {Total Links strength}, K2 percentage share weight of {total link} K3 score of {links}, C cluster

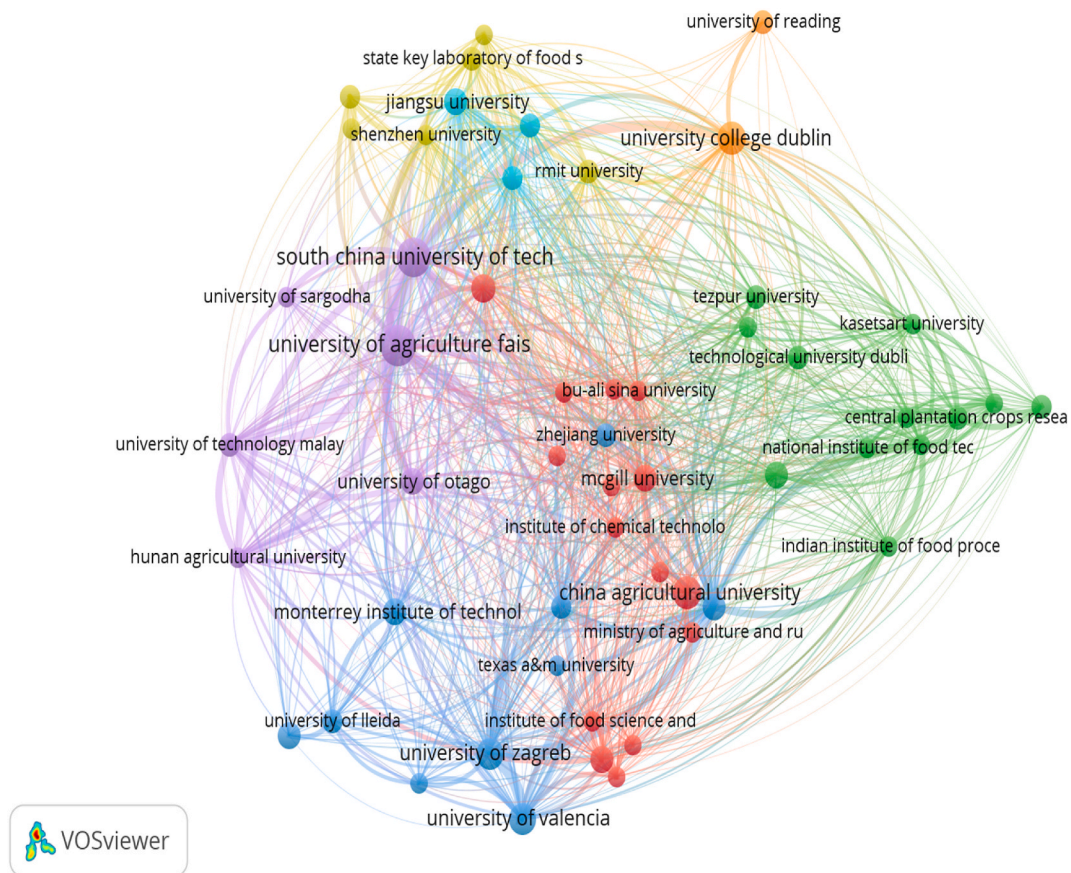


Fig. 10. network of Institutions bibliographic coupling.

size of the node and value (largeness) of flow indicate connectivity strength and importance between keywords and sources. Analysis indicate that countries used some key words frequently and most discussed in research influenced citations and links between authors, publications and sources.

3. Conclusion

The major hindrance for this noble study is it absolute dependence on data of papers from web of science. Though; web of science cover extensive range of journals, rigorously vet, complied and structured. Many journal published on fruit pasteurization in other platform could not meet the requisite standards of web of science were absent in their data base and were not capture in our analysis using VOSview. Thus, this study may not represent all research paper published on thermal and non-thermal pasteurization of fruits.

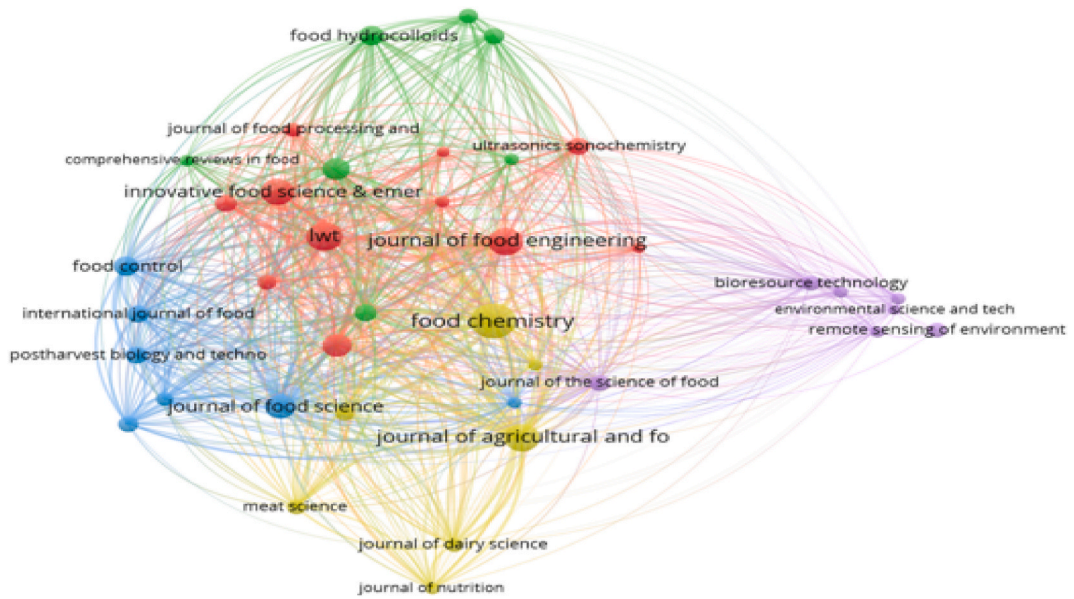


Fig. 13. network of co-citation of cited source.

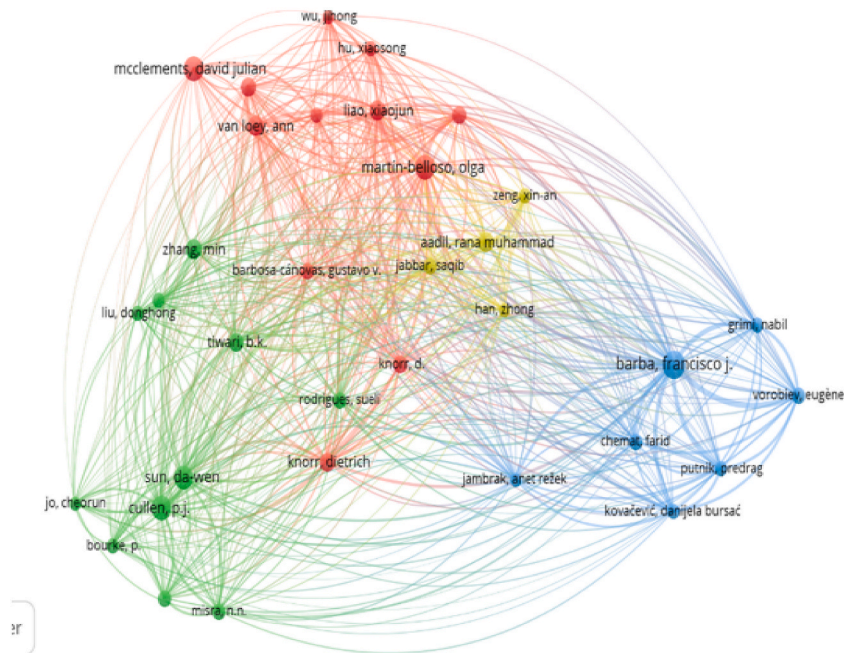


Fig. 14. network of co-citation of cited authors.

Most likely some papers were published in Scopus journals and some were captured in dimensions but not in web of science, this may reflect the level of biasment in this study base on our data base and requirement for VOSview analysis. Also; impact factor of a paper and citation are largely dependent of duration of years in publication and significant to recent research works. More new areas of research in thermal and non-thermal pasteurization of citrus fruits and foods have been identify for researchers that are interested in

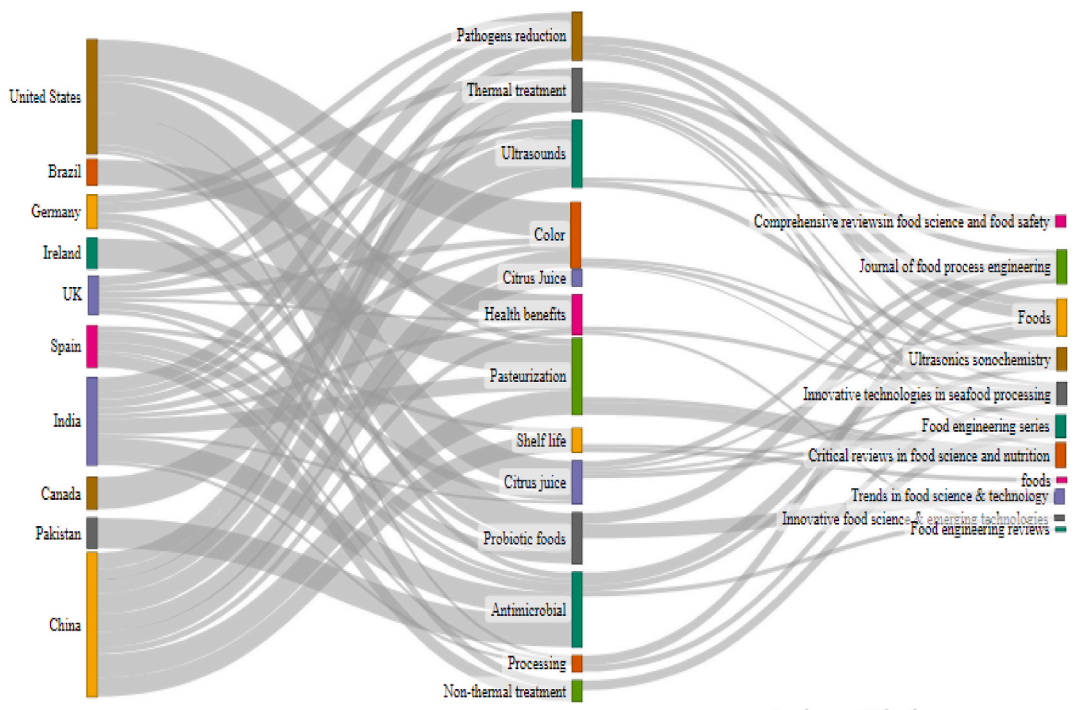


Fig. 15. Country keywords and sources correlation.

this area of research. This includes but not limited to, pulsed electric fields, high-pressure processing, ultrasound, and cold plasma, at the same instance, researching on potential benefits of hybrid approaches, aiming to optimize processes and preserve the quality, flavor, and nutritional content of citrus fruits to meet consumer demand for minimally processed foods. This study will aid scholars in food processing engineering science to call for more work and identify further research for human development and economic derivation.

Questions regarding data availability statement

Sharing research data helps other researchers evaluate your findings, build on your work and to increase trust in your article. We encourage all our authors to make as much of their data publicly available as reasonably possible. Please note that your response to the following questions regarding the public data availability and the reasons for potentially not making data available will be available alongside your article upon publication.	No
Has data associated with your study been deposited into a publicly available repository?	
Please select why. Please note that this statement will be available alongside your article upon publication.	Data will be made available on request
as follow-up to "Data Availability"	
Sharing research data helps other researchers evaluate your findings, build on your work and to increase trust in your article. We encourage all our authors to make as much of their data publicly available as reasonably possible. Please note that your response to the following questions regarding the public data availability and the reasons for potentially not making data available will be available alongside your article upon publication.	
Has data associated with your study been deposited into a publicly available repository?	

CRediT authorship contribution statement

S.A. Olaoye: Project administration, Methodology, Investigation, Formal analysis, Conceptualization. S.O. Oladele: Visualization. T.A. Badmus: Investigation. I. Filani: Resources. F.K. Jaiyeoba: Visualization. A.M. Sedara: Project administration, Methodology. A. P. Olalusi: Visualization, Validation, Supervision.

Declaration of competing interest

In this research work all authors have unanimous interest, each has no financial interest that could affect the quality of this work and each of us have contributed significantly to the work.

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Glossary

MPs: Mega Pascal

RF: Radio Frequency

HTLRT: High Temperature Low Retention Time

HPCD: High-Pressure Carbon Dioxide

nm: Nanometer

UV: Ultraviolet

HPCD: High-Pressure Carbon Dioxide

HPP: High Pressure Processing

PEF: Pulse Electric Field

SHS: Super-Heated Steam

TNP: Thermal and Non-Thermal Pasteurization

DNA: Deoxyribonucleic Acid

RNA: Ribonucleic Acid

CO₂: Carbon (Iv) Oxide

WW II: World War II

NAU: Nanjing Agricultural University

UF: University of Florida

UCD: University College Dublin

CAU: China Agricultural University

WSU: Washington State University

UAF: University of Agriculture Faisalabad

SUCT: South China University of Technology

PEF: Pulse Electric Field

LWT: Light Weight

khz: Kilohertz

EU: European Union

SCIS: Scientific Citation Indexing Service.

UCD: University College Dublin

UF: University of Florida

NAU: Nanjing Agricultural University

USA: United State of America

CAU: China Agricultural University

AI: Artificial Intelligence

IF: Impact Factor

SCUT: South China University of Technology

UAF: University of Agriculture Faisalabad

UZ: University of Zagreb

IIFPT: Indian Institute of Food Processing Technology

SSCI: Social Sciences Citation Index