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Rheological and Physical Properties Affected by the Thermal Processing of Fruit: A Bibliometric Analysis

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Abstract: This work describes a bibliometric analysis of recent articles addressing the applications of thermal processing in foods, as well as its effect on their physicochemical and rheological properties. The analysis involved utilizing the software tools VOSviewer and RStudio to map the knowledge domain. Initially, 665 articles from peer-reviewed journals were retrieved, but only 92 (13.8%) of them discussed thermal processing related to fruit applications and were published in indexed journals. However, this number was further narrowed down to 35 (5.3%) articles specifically focused on the target subject. A rigorous appraisal of these 35 articles allowed it to be classified according to its aim, kind of fruit used, thermal processing treatment, and its rheological, physicochemical, and other properties. The leading countries in the general area of food thermal processing research according to documents and citations were China, USA, Brazil, India and Spain. It is important to highlight that conventional thermal processing continues to be investigated for applications in fruits; on the other hand, it is expected that the use of unconventional or emerging technologies will bring significant advances to the food industry in the future.

Keywords: bibliometrics; thermal processing; food; fruit; rheology; physical properties

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1. Introduction

The thermal processing of foods refers to the application of heat to food products to achieve specific goals, such as improving their safety by avoiding potential contamination, prolonging their shelf life, and enhancing their physical or sensory properties. This process has been widely used in the food industry to ensure that products are safe and retain their quality throughout their intended shelf life. Advancements in thermal processing have allowed for more precise control over heating, so that temperature application can result in improvements in food properties without a loss in their nutritional aspects. Although traditional processes have been developed to preserve food and extend its shelf life without affecting the inherent qualities of food, this objective remains as a major challenge [1–4].

Among the conventional thermal processing methods used for the food industry, pasteurization, sterilization, cooking, drying, and blanching are the most cited. Pasteurization involves heating food products to a specific temperature (usually below the boiling point) for a certain period to reduce the number of harmful bacteria and extend the product's shelf life. Sterilization, on the other hand, involves heating food products to a much higher temperature (usually above the boiling point) for a long period to kill all microorganisms and spores present in the food. Cooking is a process used to make food more palatable and safer for consumption. Drying is a technique that involves removing moisture from food, reducing its water activity to inhibit the growth of microorganisms and increase the shelf life of the final product. Blanching is mainly used to reduce enzymatic activity, destroy microorganisms, and remove impurities, making food safer and prolonging its shelf life. Generally, this process is widely used in foods such as fruits and vegetables [5,6].

Thermal processing is a type of operation that can alter the chemical degradation, release, and bioavailability of bioactive components in food, thus altering its biological activity. In addition, it can change the food structure; consequently, the rheological and physicochemical properties also change. In this sense, it is important to evaluate these properties after processing to meet consumers' expectations for nutritious, tasty, convenient, safe, readily available, and high-quality food [7].

Concurrently, non-conventional and emergent technologies such as high-pressure technologies, pulsed electric fields, ultrasound, cold plasma, and other non-thermal methods, as well as their impacts on food properties, are being investigated. These technologies, which operate at ambient or sublethal temperatures, aim to minimize damage to temperature-sensitive components and offer the potential to enhance sensory and nutritional qualities when compared to traditional methods [8–19]. Consequently, some authors have suggested that these technologies may pose competition to traditional thermal techniques by mitigating the adverse impacts on nutritional and sensory quality associated with thermal degradation.

In order to justify the approach taken in this work related to heat treatment focused on fruits, currently, there is a search for fresh foods with characteristics equal to in natura, in line with a healthy and sustainable lifestyle. This modern lifestyle has increased the demand for practical and healthy products, which not only save time and effort, but also offer the benefits of fresh products, driving the fruit and fruit products market. However, all over the world, people have less time to eat properly and opt for faster meals that often do not meet the health criteria. In view of this, researchers and food producers use technology as an important ally for those who want to adopt healthier habits and not give up practicality when it comes to eating [12,14]. Regarding a healthy diet, fruits and fruit products are important sources of nutrients, while being practical to consume. However, fruits are living and breathing products that keep their metabolism active even after harvesting. They are easily perishable after harvest due to their high water activity, soft pulp texture, high metabolic activity, susceptibility to microbial contamination and sensitivity to mechanical damage, which restrict their market potential and consumer access. Therefore, it is necessary to look for methods that extend the shelf life and maintain the quality of the fruits during the post-harvest process. Among the various conservation processes used, heat treatments are the most effective and the most productive. Various heat treatments, including conventional and unconventional ones, have been reported as promising post-harvest approaches which have an effect on fruit quality [15].

The goal of this work is to present a bibliometric analysis of recent articles addressing the applications of thermal processing in foods, as well as how it affects their physicochemical and rheological properties, focusing on fruit processing.

2. Methodology

The bibliometric analysis is an essential tool for analyzing and mapping the evolution of a scientific area, facilitating the identification of emerging trends and research gaps. It also furnishes crucial information for decision making and the efficient allocation of resources in scientific research.

Through the literature databases, bibliometric analyses have the capability to recognize the most pertinent and context-specific studies, thereby offering valuable insights into research queries. This method is characterized by its transparency, replicability, and reliability, ensuring a thorough search of the literature grounded on pre-defined descriptors [20–23].

The systematic bibliometric analysis performed involved research from the Web of Science (WoS; Clarivate Analytics, London, UK) platform and was performed in five steps. Birkle et al. [20] reported that the Institute for Scientific Information (ISI) has maintained a well-established network of partners for over 50 years, which has facilitated the growth and evolution of the use of WoS.

The analysis was performed by the extraction, selection, and appraisal of all relevant studies. In Step 1, all records associated with the general topic "(food* or fruit*) and (rheolog* or "physic* propert*") and (thermal and (process* or technolog*)) not non-thermal" in the Title, Abstract and Author Keyword fields within the WoS Core Collection, published between January 1989 and December 2022 were identified. The search yielded 794 documents (Table 1), this being 665 peer-reviewed articles, 97 reviews, 41 proceedings, 13 early access, 1 book chapter, 1 correction and 1 reprint. Step 2 aimed to restrict the search only to papers published in peer-reviewed journals, totaling 665 articles.

Table 1. Classification of articles obtained in Steps 1 and 2 according to the type of publication retrieved from the Web of Science covering the general topic of the research.

Type of Document	Number
Article in peer-reviewed journals	665
Review	97
Proceeding Paper	41
Early access	13
Book chapters	1
Correction	1
Reprint	1
Total of documents	794

Note: Since a work can be classified into more than one category, the sum of the items is greater than the total number of documents.

Step 3 consisted of the extraction of articles covering fruit, and this was achieved after the further filtering of those 665 documents, resulting in a total of 92 articles. In Steps 4 and 5, these 92 selected articles were evaluated in detail to verify the adequacy of their contents, as well as to include only those that had been published within the last ten years, to bring the recent directions of this subject. The whole process yielded 35 articles, which were analyzed thoroughly and classified according to their objectives, thermal processing treatment, and the rheological and physicochemical properties, as well as other properties, of the fruit samples used. This search, extraction, filtration, and selection process is shown in a PRISMA flow diagram (Figure 1) [24].

The bibliographic data were analyzed using VOSviewer (version 1.6 15) [25,26] and RStudio (version 1.3 1093) [26,27] in order to create knowledge domain maps. Descriptive analyses of the data were carried out using the Bibliometrix package within RStudio.

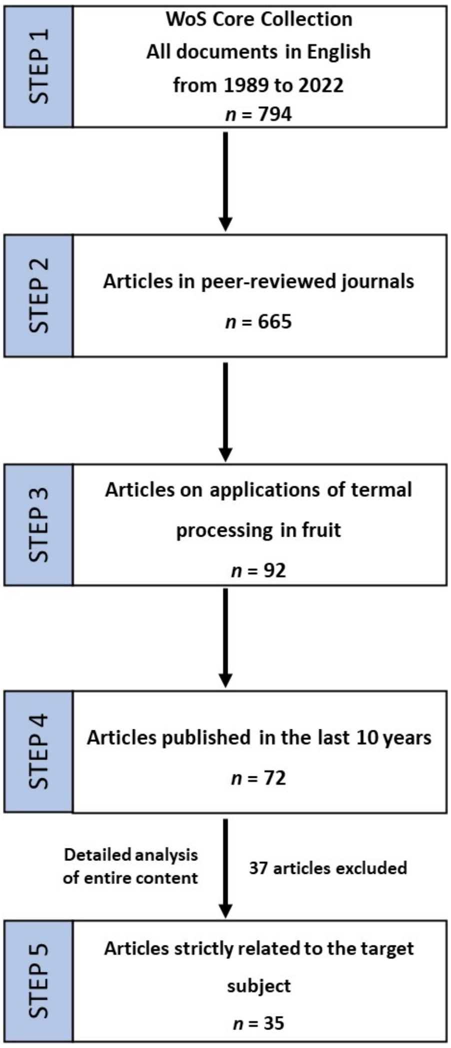

Figure 1. PRISMA flow diagram of the bibliometric analysis, indicating the number of documents retrieved from the Web of Science at each stage of the research.

3. Results

3.1. Overview Analysis

The bibliometric analysis was used as a reference of the literature selected in the WoS database regarding the applications of thermal processing in food and how it can affect the physicochemical and rheological properties of these foods, during the timeframe 1989 to 2022.

The first step retrieved 794 documents produced by 2914 authors and 910 research organizations distributed over 71 countries and indexed according to 2188 keywords. From those documents, only 92 (11.6%) were related to applications in fruits. Besides that, when taking into account only articles closely related to the target subject and published in SCIE-listed journals, the number of papers focusing on the thermal processing of fruits and the effect over their properties was reduced to 35 (4.4%).

3.2. Analysis of the Search Performed Using Topic Descriptors (Step 1 to 2)

The analysis of the articles obtained through Steps 1 and 2 of the bibliometric investigation made it possible to verify the countries, research organizations, and authors with the highest productivity, as well as the most common source journals, disciplines, cited articles, and keywords, linked to research on the thermal processing of foods with a specific focus on fruit processing. In Figure 2, the network map (visualized using VOSviewer) displays each country as a nodal disc, where the size of the node corresponds to the country's relative activity in the research into the thermal processing of food. Additionally, the links connecting the nodes depict the collaborative ties between the countries in this area of study, with thicker links indicating stronger ties. The leading countries in the general area of food thermal processing research with respective documents and citations were China (154; 23,158), the USA (89; 13,383), Brazil (59; 8872), India (49; 7368) and Spain (39; 5865), while collaborating countries showed a tendency to cluster together in some distinct groups (highlighted in colors such as orange, pink, brown and blue).

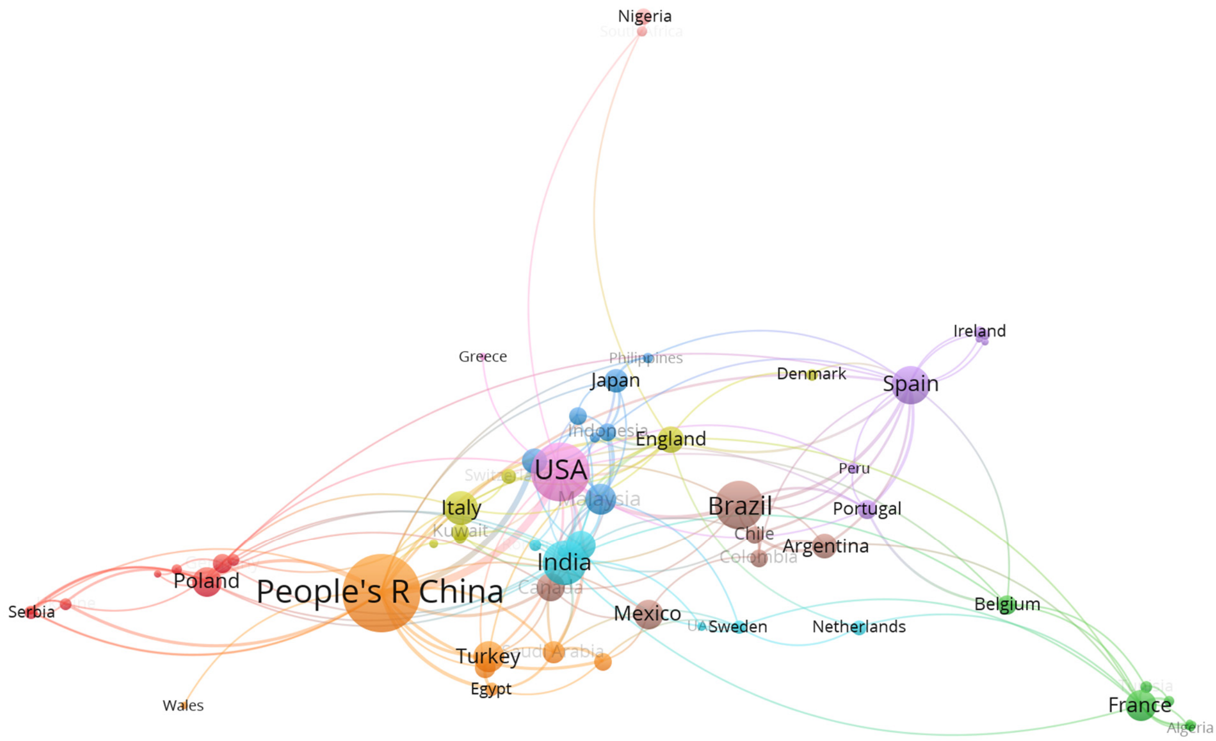

Figure 2. Network map of the contributions of countries to the general area of the thermal processing of foods.

The individual organizations with the highest numbers of publications in the area of food thermal processing research were in China, Spain, Argentina, Brazil, France and Italy (Table 2). The Jiangnan University in China and Consejo Superior de Investigaciones Cientificas—CSIC in Spain were the leading institutions in terms of publications, with 15 and 14 peer-reviewed articles, respectively.

In Figure 3, the network map illustrates the contributions of the leading research organizations to food thermal processing research, where the size of the nodal disc represents productivity and the links between nodes indicate collaboration between institutions. It can be observed that the Universidade Estadual de Campinas acts without major collaborations with other Institutions.

Table 3 presents the 10 most prolific authors in food thermal processing research, along with their research output indices and affiliated countries. In the present case, the author J. Ahmed from Kuwait was the most prolific (11 papers), followed by the Chinese authors B Li and J Li with 9 and 8 papers, respectively. In Figure 4, the knowledge domain map illustrates the contribution of various authors to food thermal processing research, where the size of the nodal disc indicates the number of co-authored articles published, and the links between nodes represent collaborative networks. The chart highlights that the collaboration clusters primarily consist of Chinese and American researchers.

Table 2. Top 10 organizations ranked according to their output in the general field of food thermal processing research.

Rank	Organization	Country	Ps	P	*h*	TC	CA	AC	CPP
1	Jiangnan University	China	15	2.26	10	331	22.07	321	21.40
2	Consejo Superior de Investigaciones Cientificas	Spain	14	2.10	8	203	14.50	201	14.36
3	Consejo Nacional de Investigaciones Cientificas y Tecnicas	Argentina	13	1.96	6	172	13.23	172	13.23
4	Universidade Estadual de Campinas	Brazil	13	1.96	6	118	9.07	117	9.00
5	Northwest A F University China	China	11	1.65	7	156	14.18	153	13.90
6	China Agricultural University	China	11	1.65	5	171	15.55	170	15.46
7	South China University of Technology	China	11	1.65	6	143	13.00	143	13.00
8	Centre National de la Recherche Scientifique	France	10	1.50	8	314	31.40	314	31.40
9	Universidade de São Paulo	Brazil	10	1.50	5	96	9.60	91	9.10
10	Consiglio Nazionale delle Ricerche	Italy	9	1.35	7	323	35.89	322	35.78

Ps, number of publications; P, percentage in relation to total number of publications in peer-reviewed journals (n = 665); *h*, *h*-index; TC, total citations; CA, citation average; AC, article citations; CPP, citation per paper.

Figure 3. Network map of the contributions of organizations to the general area of the thermal processing of foods.

Table 3. Top 10 authors ranked according to their output in the general field of thermal food research.

Rank	Author	Country	Ps	P	*h*	TC	CA	AC	CPP	TLS
1	J Ahmed	Kuwait	11	1.65	8	472	42.90	464	42.18	18
2	B Li	China	9	1.35	7	111	12.33	110	12.22	32
3	J Li	China	8	1.20	6	94	11.75	93	11.63	30
4	DJ Mcclements	USA	7	1.05	6	130	18.57	125	17.85	27
5	Y Wang	Australia	7	1.05	3	33	4.71	25	3.57	19
6	M Zhang	China	6	0.90	5	261	43.50	239	39.83	15
7	L Li	China	6	0.90	5	105	17.50	105	17.50	36
8	B Wang	China	6	0.90	4	33	5.50	31	5.17	21
9	Q Zhang	China	5	0.75	5	112	22.40	112	22.40	14
10	J Telis-Romero	Brazil	5	0.75	4	67	13.40	59	11.80	14

Ps, number of publications; P, percentage in relation to total number of publications in peer-reviewed journals (n = 665); *h*, *h*-index; TC, total citations; CA, citation average; AC, article citations; CPP, citation per paper, TLS, total link strength.

The top 10 journals, all of which were SCIE-listed, are shown in Table 4, ranked according to the number of peer-reviewed papers retrieved on the general food thermal processing topic. The leading periodical Food Hydrocolloids publish research (experimental and review papers) mainly concerning the functional properties, characteristics, and applications of hydrocolloid materials in food products. The upcoming periodicals Journal of Food Process Engineering and Journal of Food Processing and Preservation are highly specialized in the field of food processing technologies, and, despite occupying the second and third places in this ranking, both presented the lowest values of the h index, total citations, citation average, article citations and citations per paper. Except for the International Journal of Biological Macromolecules, all other journals have "Foods" in their titles. As expected, most food thermal processing studies were carried out by researchers in the disciplines of food science and technology, applied chemistry and chemical engineering.

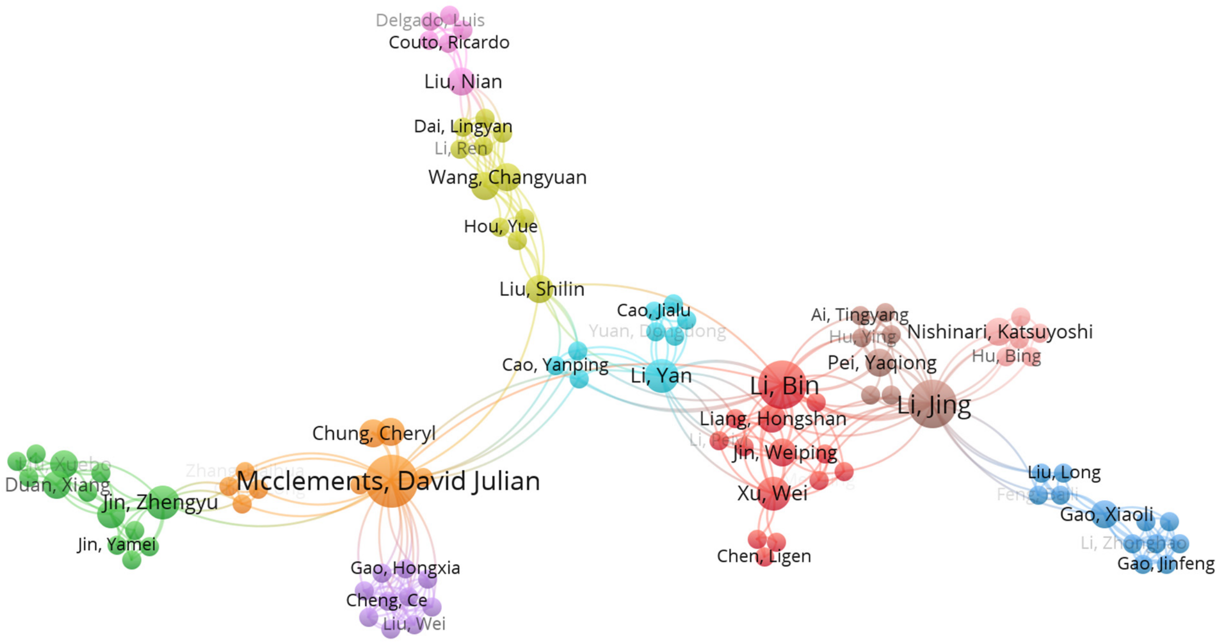

Figure 4. Network map of authors who have published in the general area of the thermal processing of foods.

Table 4. Top 10 journals and disciplines.

Rank	Journals	Country	Ps	P	*h*	TC	CA	AC	CPP
1	Food Hydrocolloids	England	50	7.52	24	1317	26.34	1297	25.94
2	Journal of Food Process Engineering	USA	28	4.21	9	244	8.71	241	8.61
3	Journal of Food Processing and Preservation	USA	24	3.61	8	180	7.50	179	7.46
4	LWT Food Science and Technology	The Netherlands	22	3.31	11	511	23.22	511	23.22
5	International Journal of Biological Macromolecules	The Netherlands	21	3.16	14	662	31.52	654	31.14
6	Food Chemistry	England	21	3.16	12	484	23.05	478	22.76
7	Journal of the Science of Food and Agriculture	USA	20	3.00	10	329	16.45	329	16.45
8	Journal of Food Engineering	England	19	2.86	15	455	23.94	452	23.79
9	Innovative Food Science Emerging Technologies	England	18	2.70	11	366	20.33	363	20.17
10	Food Research International	The Netherlands	17	2.56	12	345	20.29	344	20.24
Rank	Disciplines	Country	Ps	P	*h*	TC	CA	AC	CPP
1	Food Science and Technology	-	396	-	42	6951	17.55	6576	16.61
2	Applied Chemistry	-	151	-	37	3588	23.76	3494	23.14
3	Chemical Engineering	-	89	-	22	1384	15.55	1372	15.42
4	Polymer Science	-	80	-	27	1928	24.10	1895	23.68
5	Biochemistry/Molecular Biology	-	43	-	19	1047	24.35	1038	24.14
6	Chemistry, Multidisciplinary	-	37	-	12	743	20.08	739	19.97
7	Agriculture, Multidisciplinary	-	35	-	12	609	17.40	608	17.37
8	Nutrition and Dietetics	-	31	-	13	577	18.61	570	18.39
9	Physical Chemistry	-	23	-	11	797	34.65	794	29.40
10	Materials Science, Multidisciplinary	-	18	-	10	533	29.61	531	29.50

SCIE, Science Citation Index Expanded; Ps, publications; P, percentage; *h*, *h*-index; TC, total citations; CA, citation average, AC; article citations; CPP, citations per paper. Data relate to articles published in peer-reviewed journals (n = 665).

Figure 5 illustrates the number of articles published per year and their citations in order to understand the trend in this topic. There has been a growing increase in publications on this topic in the last 10 years, as well as a consequent increase in the respective citations.

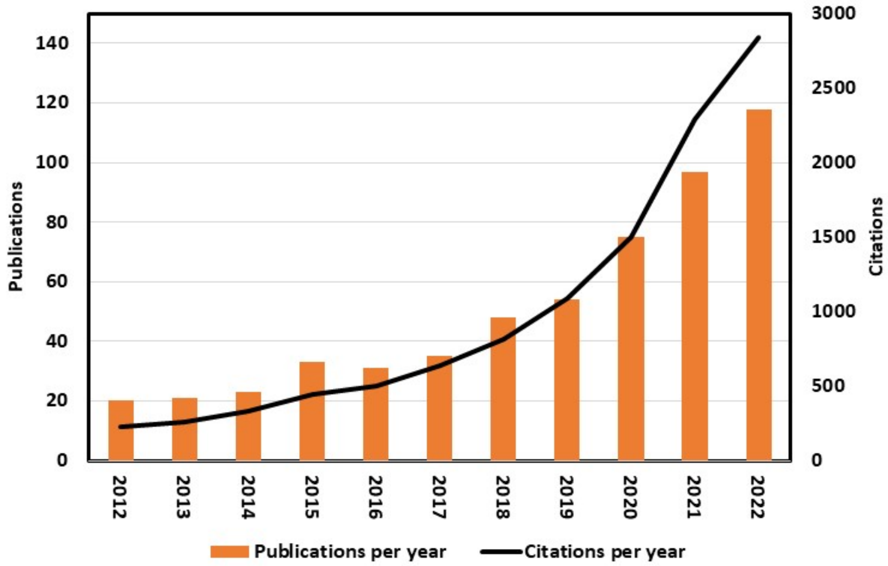

Figure 5. Publications and citations per year in the general area of the thermal processing of foods.

The 10 most cited food thermal processing articles [28–37] in the WoS database are listed in Table 5 and relate to studies published during the period from 1997 to 2013. As expected, most of these papers deal with samples of foods, except the top-ranked article by Ahmed et al., (2011), which provides a review of green packaging technology made from polylactides [28], as well as that of Barreca et al. (2007), who studied ZnO-TiO_2 nanocomposites [35].

In the next sections, how thermal processing affects the physicochemical and rheological properties of fruits will be described. This reasoning was built from the detailed analysis of the 35 papers obtained in Step 5 (see Figure 1).

The most used keywords in the articles analyzed are identified in Figure 6. The frequency of occurrence of the keywords indicates that the most used terms highlighted for the works in this area were rheology, rheological properties, thermal properties, antioxidant activity, starch properties, microstructure and functional properties. However, various other terms such as stability, crystallinity, gelation, texture and thermal treatment also occurred with some frequency.

3.3. Conventional Thermal Processing

The conventional thermal treatment is essentially based on generating heat and transferring it to the product through forms of heat expression (conduction and convection). Fruits are very perishable feedstock; therefore, the application of thermic treatment is the standard to assist their preservation, due to its capability to decrease deterioration, pathogenic microorganisms and enzymes that accelerate ripening. In addition, thermal treatment is a commonly used technology in the food industry and ensures the microbiological quality, and sensory and physicochemical characteristics of the products.

This review summarizes 35 articles that explain the application of different thermal processes, and 21 of these works have addressed the use of conventional thermal treatments [1–19,38–53]. Table 6 shows a summary discussion about some of the conventional thermal processing techniques used in in natura fruits and in their sub-products, such as flours, juices, pulps, husks, almonds, etc. Conventional heating such as oven drying, sun drying, water baths, pasteurization, UHT (Ultra-High-Temperature), HTTP (high-pressure thermal processing), and HPP (high-pressure processing) are discussed here, as well as their effects.

Table 5. Top 10 most cited papers.

Rank	Title	Year	Journal	Authors	Citations
1	Polylactides-Chemistry, Properties and Green Packaging Technology: A Review	2011	International Journal of Food Properties	Ahmed, Jasim; Varshney, Sunil K. [28]	241
2	All gelatin networks: 1. Biodiversity and physical chemistry	2002	Langmuir	Joly-Duhamel, C; Hellio, D; Djabourov, M. [29]	188
3	Production of antioxidant high dietary fiber powder from carrot peels	2008	LWT-Food Science and Technology	Chantaro et al. [30]	185
4	Effects of thermal treatment and sonication on quality attributes of Chokanan mango (*Mangifera indica* L.) juice	2013	Ultrasonics Sonochemistry	Santhirasegaram et al. [31]	162
5	Characteristics of cellulose nanofibers isolated from rubberwood and empty fruit bunches of oil palm using chemo-mechanical process	2011	Cellulose	Jonoobi et al. [32]	151
6	Extrusion process improves the functionality of soluble dietary fiber in oat bran	2011	Journal of Cereal Science	Zhang, Min; Bai, Xin; Zhang, Zesheng [33]	151
7	Rheological and DSC study of sol-gel transition in aqueous dispersions of industrially important polymers and colloids	1997	Colloid and Polymer Science	Nishinari, K. [34]	145
8	First example of ZnO-TiO_2 nanocomposites by chemical vapor deposition: Structure, morphology, composition, and gas sensing performances	2007	Chemistry of Materials	Barreca et al. [35]	141
9	Effect of mechanical and thermal treatments on the microstructure and rheological properties of carrot, broccoli and tomato dispersions	2011	Journal of the Science of Food and Agriculture	Lopez-Sanchez et al. [36]	133
10	Emulsification mechanisms and characterizations of cold, gel-like emulsions produced from texturized whey protein concentrate	2009	Food Hydrocolloids	Manoi, Khanitta; Rizvi, Syed S. H. [37]	119

Figure 6. Main keywords used in the study of rheological and physical properties affected by the thermal processing of foods.

Table 6. The 35 articles strictly related to the thermal processing in fruit applications (step 5).

References	Objectives	Fruit	Thermal Processing Treatment	Rheological Properties	Physicochemical Properties	Other Properties
Chumroenvidhayakul et al., 2022 [6]	To examine both the physicochemical and functional attributes of DFP derived from hospital food waste. Additionally, the study delved into the impact of DFP on in vitro starch digestibility, pasting behavior, and gelatinization when combined with different types of flours commonly used in Asia, including potato, glutinous rice, rice, and wheat flour.	Dragon-fruit peel waste	The fresh dragon-fruit peel was cleaned to remove impurities and dried at 60 °C for 12 h using a hot air oven.	The pasting profile of flours, including peak viscosity (PV), trough, breakdown (BD), final viscosity (FV), setback, and pasting temperature.	Proximate compositions, bioactive compounds and antioxidant activity of DFP; pectin [equivalent weight (EW) (g/mol), methoxyl content MeO (%); degree of esterification DE (%), total anhydrouronic acid AUA (%)]; and physicochemical properties of DFP [oil holding capacity, OHC (g of Oil/g of Sample), water holding capacity, WHC (g of Water/g of Sample), and swelling capacity, SC (mL of water/g of sample)].	The effect of DFP on in vitro starch digestion, hydrolysis index and starch fraction; effect of DFP on total phenolic content, total betanin content, and antioxidant activity during in vitro digestion; effect of DFP and various types of flour on thermal properties [onset temperature (To), peak temperature (Tp), conclusion temperature (Tc) and gelatinization enthalpy (DH)].
Kaveh et al., 2022 [9]	To optimize the independent variables (microwave power, kiwi sample thickness, and US treatment time) and investigate the dependent variables (drying time, effective moisture diffusion, specific energy consumption, color, and shrinkage) for kiwifruits subjected to ultrasound treatment prior to microwave drying, utilizing a Response Surface Methodology (RSM) approach.	Kiwi	Microwave power and ultrasound.	Not evaluated.	Thermal properties (drying time, effective moisture diffusion (Deff), specific energy consumption (SEC)), and quality (color and shrinkage).	Not evaluated.

Table 6. *Cont.*

References	Objectives	Fruit	Thermal Processing Treatment	Rheological Properties	Physicochemical Properties	Other Properties
Li et al., 2022 [8]	The red-dragon-fruit peel's betalains were extracted through ultrasound techniques, followed by the preparation of betalain microcapsules using maltodextrin as the wall material, assisted by ultrasound and freeze-drying. Furthermore, the study explored the influence of ultrasound treatment on the physicochemical properties and antioxidant activity of the betalain microcapsules.	Red-dragon-fruit peel	Ultrasound	Not evaluated.	Concentration of betalains and extraction yield; thermal stability of betalains; encapsulation efficiency of betalains; particle size of betalain microcapsules and Zeta potential were determined using dynamic-light-scattering technique, thermal analyses of betalain microcapsules (DSC), and antioxidant activity of betalain microcapsules (DPPH).	Morphology of betalain microcapsules; chemical structure of the betalains, maltodextrin, and betalain microcapsules; partial size and Zeta potential; morphology of betalain microcapsules; and degradation rate constant.
Asmat-Campos et al., 2022 [43]	To develop a closed-flow solar dehydration system coupled with a refrigeration-assisted inverse-sublimation and moisture-removal process.	Pouteria lucuma	The lucuma fruit was dehydrated using equipment, including devices to absorb thermal energy from incident sunlight, such as a Trombe wall and a parabolic cylindrical collector, and a thermo bank system. In addition, the influence of three types of heat-transfer fluids (water, oil and oil nanofluid, silver nanoparticles) was evaluated.	Not evaluated.	Humidity, protein, fat, carbohydrate and ash soluble solids.	Organoleptic properties.

Table 6. *Cont.*

References	Objectives	Fruit	Thermal Processing Treatment	Rheological Properties	Physicochemical Properties	Other Properties
Habibiasr et al., 2022 [1]	To examine the impact of drying palm kernel and kernel oil at 80 °C, this study investigated changes in fatty acid composition, color, content, functional groups, thermal degradation, and morphology.	Palm kernel	80 °C in a conventional oven.	Not evaluated.	Red and yellow color.	Free fatty acid; investigation of microstructure using scanning electron microscopy (SEM).
Ramamurthy and Krishnan, 2022 [5]	To comprehend how viscosity affects thermal patterns within a sealed container containing homogeneous liquid, by contrasting it with pure-conduction simulations. Using computational fluid dynamics (CFD) simulations, the research examined how viscosity influences thermal behavior during the thermal processing of a sealed container.	Carboxyl Methyl Cellulose (CMC) solutions.	Process conditions of a standard thermal treatment process at 80 °C.	Viscosity.	Not evaluated.	Kinetic parameters of the destruction of Clostridium sporogenes (D, Z value); integrated lethality factor (F).
Andreone et al., 2022 [12]	To explore how various non-caloric and reduced-calorie sugar blends affect the physicochemical, rheological, and sensory characteristics of sweet confectioneries.	Sweet confectioneries using low-methoxyl pectin, orange juice preserved by UV-C light, with sucrose partially or completely replaced.	The diluted juice was processed in a pilot-scale self-made UV-C unit.	Viscosity; instrumental texture evaluation (hardness 1 during the first compression cycle, hardness 2 during the second compression cycle, area 1 under the curve during the first compression, area 2 under the curve during the second compression); cohesiveness; adhesiveness to palate; springiness; gumminess; and viscoelastic properties.	Soluble solids; water activity; pH, water-holding capacity; turbidity; color measurement (L* (lightness), a* (green-red) and b* (blue-yellow)).	Not evaluated.

Table 6. *Cont.*

References	Objectives	Fruit	Thermal Processing Treatment	Rheological Properties	Physicochemical Properties	Other Properties
Alves et al., 2021 [13]	To provide the initial comprehensive assessment of the kinetic triplet and thermodynamic parameters during the pyrolysis of açaí seeds (*Euterpe oleracea*), the primary biowaste generated by the açaí-fruit processing industry.	Açaí seed	The sample was dried until constant mass using a forced-air drying oven at 105 °C.	Not evaluated.	Physicochemical analyses: volatile matter, fixed carbon, and ash; fractions of carbon (C), hydrogen (H), nitrogen (N), oxygen (O), and sulfur (S) in the biomass; calorific values; bulk density; bioenergy density; chemical composition (contents of hemicellulose, cellulose, and lignin); thermogravimetric analysis; pyrolysis kinetics (Ea, A, and f(α)); and thermodynamic analysis (ΔH, ΔG, and ΔS).	Not evaluated.
Rahib et al., 2021 [39]	To conduct a comprehensive analytical characterization of argan biomasses to assess their potential as an energy source. Initially, physicochemical analyses were performed, followed by an evaluation of thermal behavior using thermoanalytical techniques to assess thermal properties and investigate the impact of high temperatures. The study also established correlations between physicochemical properties, thermal conductivity, and thermogravimetric combustion parameters.	Argan fruit residues (AFRs)	Sun dryer.	Not evaluated.	Moisture; ash; volatile matter; fixed carbon; true density; bulk density; carbon, hydrogen, nitrogen, sulfur and oxygen content of AFRs; calorific value of AFRs [HHV high heating value, NHV net heating value, ED energy density]; CHO index of AFRs; thermal characteristics: TG, DTG and DTA profiles during pyrolysis, TG, DTG and DTA profiles during combustion; thermal conductivity; and thermal diffusivity.	Not evaluated.

Table 6. *Cont.*

References	Objectives	Fruit	Thermal Processing Treatment	Rheological Properties	Physicochemical Properties	Other Properties
Zhou et al., 2021 [45]	To optimize the extraction condition of polysaccharides from fruit shells of Camellia oleifera (CFP) by applying response surface methodology. The characteristic structure was assessed, and the antioxidant ability of polysaccharides was evaluated.	Fruit shells of Camellia oleifera (CFP)	The extraction of polysaccharides from the shells was carried out using hot extraction with the assistance of ultrasound. Distilled water was mixed with the powder in different solvent-to-sample ratios (10, 20, 30, 40 and 50 mL/g) under various temperatures (30, 40, 50, 60 and 70 °C) for 20, 30, 40, 50 and 60 min with serial powers of ultrasound (240, 280, 320, 360 and 400 W).	Not evaluated	Total polysaccharides; total reducing power of CFP; total protein; and monosaccharide components.	Antioxidant-potential in vitro assays; antioxidant potential of CFP in vivo.
Martinez-Solano et al., 2021 [14]	To present advances and recent studies comparing ultrasound-assisted extraction (UAE) and conventional extraction methods for the specific fiber compounds of fiber-rich by-products, not only to evaluate the extraction yield and processing variables but also to compare the composition and techno-functionality of the extracted compounds and their benefits in food applications, which can contribute to the future utilization of US in the food industry.	Compounds from fiber-rich by-products.	Ultrasound (US)-assisted extraction (UAE)	Viscosity	Swelling capacity; water-holding capacity; oil-holding capacity; polysaccharides; and pectin.	Antitumor activity; hypolipidemic effect; and antioxidant capacity.

Table 6. *Cont.*

References	Objectives	Fruit	Thermal Processing Treatment	Rheological Properties	Physicochemical Properties	Other Properties
Sonawane et al., 2020 [3]	To study and analyze the effects of processing temperature (30–75 °C) on dynamic rheology and color degradation kinetics of bael fruit pulp.	Bael	Processing at temperatures between 30 and 75 °C.	Dynamic rheological properties: storage modulus, loss modulus and complex shear modulus.	Total solid content; pH; moisture content; and color degradation kinetics.	Not evaluated.
Buniowska et al., 2020 [38]	To investigate the effects of thermal processing on the physicochemical properties, steviol glycosides, bioactive compounds, and antioxidant degradation capacity of a beverage based on exotic fruit juices, orange juice, açaí, and oat, and sweetened with *Stevia rebaudiana* water extracts at different concentrations.	Fruit juices (papaya–mango–orange) mixed with açaí and sweetened with stevia.	The experiments were carried out using a plate-and-frame heat exchanger equipped with a nominal 66 s hold-time tube (FT74X/HTST/UHT, Armfield, Inc., Millstone Township, NJ, USA). The samples were pasteurized by using a temperature of 88–99 °C for 15–30 s.	Not evaluated.	Turbidity index; pH; browning index; color (lightness, blueness, redness); hydroxymethylfurfural (mg/L); rebaudioside A (mg/100 mL); rebaudioside C (mg/100 mL); rebaudioside F (mg/100 mL); stevioside (mg/100 mL); ascorbic acid (mg/100 mL); total carotenoids (μg/100 mL); total anthocyanins (mg/100 mL); TEAC (mM TE) [antioxidant capacity measured as TEAC values]; and ORAC (mM TE) [antioxidant capacity measured with ORAC assay].	Not evaluated.
Xiang et al., 2020 [15]	To evaluate the fungicidal activity of UVC-LEDs emitting at 275 nm against Zygosaccharomyces rouxiiin apple juice.	Apple	Ultraviolet-C light-emitting-diode (UVC-LEDs) irradiation.	Not evaluated.	pH; electrical conductivity; total titratable acidity; total soluble solids; reducing sugars; and color parameters: L*, a*, b*, the Chroma (C*), hue angle (H*), and total color difference (ΔE*ab).	Antioxidant capacity; microbial enumeration; total phenolic content; and browning index.

Table 6. *Cont.*

References	Objectives	Fruit	Thermal Processing Treatment	Rheological Properties	Physicochemical Properties	Other Properties
Han et al., 2020 [44]	To prepare biodegradable mandarin peel pectin (MPP) films using mandarin peel and to examine the physicochemical properties of the MPP films containing SLE as an antioxidant packaging film.	Mandarin peel, sage leaf.	Heating at 85 °C, sonicated.	Mechanical properties of the film (tensile strength and elongation at break).	Color of the film (L*, a* and b*) and transparency; water-vapor permeability; moisture content; water solubility; thermogravimetric analysis; optical properties; and water vapor permeability.	Total phenolic content; antioxidant properties; ABTS radical-scavenging activity; DPPH radical-scavenging activity; ferric-reducing antioxidant power; ferrous-ion-chelating activity; and microstructure of the MPP films using scanning electron microscopy.
Velasco et al., 2020 [2]	To evaluate the effect of moderate thermal treatments on the inactivation of L. monocytogenes and the physicochemical quality of soursop pulp, to determine the best processing conditions that allow the maintenance of quality and achievement of an adequate safety level.	Soursop	Thermal treatments through capillaries.	Not evaluated.	Color parameters, L*, a*, and b*; total color difference (ΔE); total soluble solids; pH; titratable acidity; ascorbic acid content; total sugars; and reducing sugars.	Microbiological analyses; counts of total coliforms, aerobic mesophiles, E. coli, yeasts, and molds; browning index; and total phenolic content.
Benjamin and Gamrasni, 2020 [46]	To provide a comprehensive analysis of the microbial, nutritional, and/organoleptic qualities of pomegranate juice after being processed using HPH (100 and 150 MPa) in comparison to thermal pasteurization (55 to 75 °C). In addition, the possibility of improving the outcome by combining the two technologies was examined.	Pomegranate juice	The juice was divided into four groups: (1) untreated control; (2) low-temperature pasteurization (55, 65, or 75 °C for 15 s) in a semi-industrial UHT facility (FT74XTS, Armfield, Hampshire, UK); (3) HPH (100 or 150 MPa) using an APV 2000 homogenizer (SPV flow, Soeborg, Denmark);	Not evaluated.	pH; titratable acidity; total soluble solids; color parameters (L*, a*, and b*); total color difference (ΔE); total polyphenol content; and ascorbic acid content.	Antioxidant activity; browning index; microbial levels (total bacteria and yeast); and sensorial quality using e-tongue and e-nose.

Table 6. *Cont.*

References	Objectives	Fruit	Thermal Processing Treatment	Rheological Properties	Physicochemical Properties	Other Properties
			or (4) combined treatment (HPH at 150 MPa followed by low-temperature pasteurization at 55 or 65 °C for 15 s).			
Shinwari & Rao, 2020 [7]	To investigate the effect of jam formulation ingredients on the rheological properties of the high-pressure-processed (HPP) jam to obtain a reduced-sugar product, and to compare the overall quality attributes of the HPP and thermal-processed jam samples.	Sapodilla jam obtained from mature sapodilla (*Manilkara zapota* cv. Kalipatti) fruits.	Thermal processing at 105 °C.	Viscosity	Water activity; pH; total soluble solids; titratable acidity; moisture content; and total phenol content.	Fourier-transform infrared spectroscopy; microbiological analysis (aerobic mesophiles, total coliforms, psychrotrophs, and yeast and mold count).
Lammerskitten et al., 2019 [17]	To analyze the impact of the pulsed electric field (PEF) pre-treatment of apple tissue on the kinetics of freeze-drying preceded by vacuum freezing, and the physical properties of such processed material.	Apple	Pulsed electric field; Freeze-drying preceding vacuum freezing.	Not evaluated.	Specific energy intake; electric-field strength; effective water-diffusion coefficient; crystallinity; hygroscopic properties; water activity; rehydration properties; and loss of soluble solids	Not evaluated.
Wibowo et al., 2019 [4]	To investigate quality changes in kale purée as affected by thermal processing and subsequent storage, to identify the combinations of thermal processing and storage that allow a high-quality product to reach the consumer.	Kale purée	The fresh kale purée was thermally treated in a multipurpose UHT pilot plant unit under different temperature intensities: a low intensity, 70 °C for 120 s for frozen storage, followed by thawing and a two-day storage under refrigerated conditions	Not evaluated.	Color parameters (L*, a*, and b*); total color difference (ΔE); pH; total soluble solids; organic acid and sugar profile; particle size distribution; and total vitamin C.	Total chlorophyll content; enzyme activity (polyphenol oxidase and peroxidase, pectin methylesterase); Bostwick consistency; and processing-intensity impact.

Table 6. *Cont.*

References	Objectives	Fruit	Thermal Processing Treatment	Rheological Properties	Physicochemical Properties	Other Properties
			(TP70); a medium intensity, 90 °C for 75 s for refrigerated storage (TP90); and a high intensity, 128 °C for 75 s for ambient storage (TP128).			
Kumar et al., 2019 [47]	To investigate the influence of varying temperatures in a convective dryer on the thin-layer drying kinetics of banana slices and to infer their influence on its rheological properties, coupled with the rehydration, nutritional quality, microstructure, thermal properties, and sensory quality of the banana slices or powder.	Banana slices or powder.	The blanched banana slices were dried at temperatures of 45, 55, and 65 ± 2 °C using a laboratory-scale electrical cabinet drier.		Total sugar; total starch; resistant starch; amylose; protein; fat; ash; ascorbic acid; sodium; potassium; calcium; phosphorous; magnesium; percent of water; swelling capacity; equilibrium moisture content; color (L*, a*, b*, whiteness index, and yellowness index); titratable acidity; solubility; and amylose content.	Nonenzymatic browning; sensory evaluation (visual appearance, dryness, touch feel, flavor after taste, texture, bitterness, and degree of acceptability); rehydration ratio; and coefficient of rehydration.
Gao et al., 2019 [16]	To investigate the influence of cold ultrasound treatment (CUT) on raw tomato juice and to infer their influence on the physical stability, nutritional value, microbial safety, and rheological parameters (viscosity, thixotropy and shear-thinning tendency).	Raw tomato juice	Cold ultrasound treatment (CUT, 87.52 W/cm^2, 10 °C).	Apparent viscosity; shear stress and shear rate; storage modulus (G′) and loss modulus (G″).	Total soluble solid; pH; titratable acidity; cloud stability; ascorbic acid; total phenolic content; color (lightness (L*), redness (a*) and yellowness (b*)); soluble pectin; and carotenoids.	Antioxidant activities; bioaccessibility; and microbial characterization (total plate count).

Table 6. *Cont.*

References	Objectives	Fruit	Thermal Processing Treatment	Rheological Properties	Physicochemical Properties	Other Properties
Luciano et al., 2018 [41]	To assess the rheological behavior of jackfruit-seed-starch (JSS) dispersions, with a particular interest on the effects of the starch extraction techniques.	Jackfruit seed	Jackfruit seed starch (JSS) was dried at 30 °C for 24 h.	Rheological characterization: strain and frequency sweeps; temperature ramp sweep; gelatinization kinetics; viscoelastic and gelatinization characteristics of the starch samples; and flow curves.	Soluble solid content; thermogravimetric analysis; bioenergy density; chemical composition; and proximate analysis.	Not evaluated.
Altemimi et al., 2018 [18]	To construct a continuous nonthermal juice pasteurizer (CNTJP) using an electric field (EF) with an alternating current, and to study the effect of voltage gradients (X1) and mass flow rates (X2) on the physicochemical properties of the phytochemical compounds along with the antioxidant capacity and antimicrobial activity, of dried lime juice.	Dried key lime juice	Conventional thermal processing at 90 °C for 15 min, and nonthermal juice pasteurization using an electric field (EF).	Not evaluated.	Total soluble solid values; pH; titratable acidity; ascorbic acid content; and total phenolic content.	Microbiological analysis (total viable count, coliform bacteria, yeast, and mold); antioxidant activity; and electrical conductivity.
Cordoba et al., 2018 [51]	To investigate the green-banana starch structure obtained from three fruits of two genotypes of genomic groups of banana: Terra Plátano (AAB), Caturra Cavendish (AAA) and Prata Anã (AAB).	Groups of bananas: Terra Plátano (AAB), Caturra Cavendish (AAA) and Prata Anã (AAB).	The aqueous extraction method was employed to separate the starch from flour efficiently. The pulp was dried and ground. The flour obtained was suspended in water and heated at 95 °C for a few minutes and then cooled to 50 °C.	Viscosity	Resistant starch content.	Differential scanning calorimetry (DSC); TGA analysis; x-ray diffraction; scanning electron microscopy (SEM); and optical microscopy.

Table 6. *Cont.*

References	Objectives	Fruit	Thermal Processing Treatment	Rheological Properties	Physicochemical Properties	Other Properties
Wu et al., 2018 [53]	To investigate the basis of viscosity differences in industrial processing products, from hot break (HB) or cold break (CB) conditions, focusing on the rheological behavior of tomato sera, separated pulp particles, and overall tomato products, in relation to the chemical composition of the HB and CB tomato sera described in previous publications.	Tomato, tomato serum.	Cold break (CB) at 77.2 °C and hot break (HB) at 93.3 °C.	Viscosity; viscoelastic properties (storage modulus (G') and loss modulus (G'')).	Pulp particle weight (ratio and solid content); pH; moisture; and particle size analysis.	Not evaluated.
Takahashi et al., 2017 [42]	To evaluate the influence of solar and oven drying on the physicochemical properties of hihatsumodoki fruits.	Hihatsumodoki	Solar and oven drying.	Not evaluated.	Physical-attribute measurements: linear dimensions (length [mm] and diameter [mm]) and mass of each fruit (g); water-activity analyses; color analysis: chromatic parameter values L*, a*, b*, and DE*; and total phenolic content analysis.	Piperine analysis: piperine contents of the dried pepper samples; DPPH radical-scavenging activity.
Mansor et al., 2017 [19]	To investigate the effect of a quartz glass sleeve on the physicochemical properties and microbial activity of pineapple fruit juice during storage. UV-C radiation is one of the nonthermal technologies that have been introduced in the food industry.	Pineapple	UV-C radiation	Not evaluated.	Temperature of juice before and after treatment (C); pH, ascorbic acid, total soluble solid, color changes in terms of L*, a* and b*, the hue angle and chroma; and microbiological analysis: number of bacteria of Salmonella typhimurium.	Not evaluated.

Table 6. *Cont.*

References	Objectives	Fruit	Thermal Processing Treatment	Rheological Properties	Physicochemical Properties	Other Properties
Hulle et al., 2017 [10]	To formulate an Aloe vera–lychee mixed beverage (ALMB) using a fuzzy logic approach, with the aim of finding the maximum acceptable level of Aloe vera in ALMB. Further, the effect of high-pressure thermal processing on quality changes in ALMB was studied and the optimum processing condition evaluated based on the desired quality attributes of the beverage.	Formulation of Aloe vera–lychee mixed beverages (ALMB).	High-pressure thermal processing (HPTP) was carried out in a lab-scale HPP unit, having a vessel capacity of two liters and a maximum working capacity of up to 900 MPa.	Not evaluated.	Total soluble solids; pH; titratable acidity; ascorbic acid; color parameters L* (lightness), a* (redness) and b* (yellowness), total color difference (ΔE*); and total phenolic content.	Antioxidant capacity; enzyme activity (pectinmethylesterase and polyphenoloxidase); and microbiological analysis (aerobic mesophiles, yeast and molds, total coliforms, lactic acid bacteria and psychrotrophs).
Jafari et al., 2017 [48]	To introduce nanofluid technology for the thermal processing of food products for the first time, increasing the heat-transfer efficiency in shell-and-tube exchangers by nanofluids and frugality in energy consumption for pasteurization, reducing thermal-processing duration, and the better-quality (lycopene, vitamin C, color, brix, pH and total microbial count) retention of food products.	Watermelon juice	Alumina–water nanofluids (2 and 4% concentrations) during high-temperature short-time processing (75, 80 and 85 °C for 15, 30 and 45 s) of watermelon juice in a shell-and-tube exchanger.	Not evaluated.	Lycopene content; lycopene retention; vitamin C content; vitamin C retention; color analysis (L* (brightness), a* (red–green), b* (yellow–blue) and total color difference (ΔE*)); total soluble solid; and pH.	Not evaluated.
Han et al., 2016 [40]	To optimize the microwave-assisted extraction (MAE) process of *O. dillenii* Haw prickly-pear fruits (OFPP) using the Box–Behnken design (BBD), with a quadratic regression model built using RSM.	*Opuntia dillenii*	Dried at 60 °C for 36 h in a hot-air oven.	Viscosity; rheological properties; flow curve; strain sweeps; and frequency sweep.	Infrared thermogravimetric analysis.	Scanning electron microscopy (SEM).

Table 6. *Cont.*

References	Objectives	Fruit	Thermal Processing Treatment	Rheological Properties	Physicochemical Properties	Other Properties
Yadav et al., 2016 [52]	To develop a mango RTS beverage fortified with whey protein and to evaluate the impact of production on the rheological behavior of the beverage.	Mango ready-to-serve (RTS) fortified with modified whey protein.	Pasteurized at 85 °C for 15 min in water bath.	Steady-state rheology (apparent viscosity, flow behavior index and consistency index); apparent viscosity profile and changes in apparent viscosity of pasteurized and unpasteurized mango; shear rate–shear stress relationship.	Protein solubility index; water holding capacity; and degree of hydrolysis.	Sensory evaluation (consistency, taste, bitterness, flavor and overall acceptability); microbiological analysis (total plate count, coliforms, yeast and mold).
Kaya et al., 2015 [11]	To evaluate the effect of UV-C irradiation and heat treatment on *E. coli* K12 (ATCC 25253) in a newly formulated lemon–melon juice (LMJ) blend; to assess the changes in the physicochemical properties of the control (untreated), UV-C-irradiated and heat-treated LMJ blends immediately after processing and after one month of refrigerated storage by means of multivariate data analysis.	Lemon and melon.	UV-C irradiation and heat treatment.	Not evaluated.	Total soluble solids; pH; titratable acidity; absorption coefficient; turbidity; and color (L*, a*, b*, ΔE).	Thermal-inactivation kinetic parameters (D and z values); microbiological analysis (total aerobic bacteria, total coliforms, yeasts and molds).
Gomathy et al., 2015 [49]	To determine the changes in the electrical conductivity, and biochemical and rheological properties of papaya pulp upon ohmic heating.	Papaya pulp	Pasteurization by ohmic heating at 96 ± 1 °C (1, 2 and 3 min).	Rheological properties: yield stress (τ); consistency (K); and flow index (n).	Electrical conductivity; bacterial load; yeast load; ascorbic acid; lycopene; and β-carotene.	Not evaluated.
Cassano et al., 2014 [50]	To investigate the rheological behavior of the concentrated blood-orange juice prepared from the clarified juice, by using thermal evaporation and osmotic distillation processes as a function of solid concentration.	Concentrated blood-orange juice.	Thermal evaporation and osmotic distillation processes.	Viscosity	Total soluble solids	Not evaluated.

In these articles, in which conventional heat treatments were applied, the authors related that there is a concern when analyzing the impact of temperature on the stability of the bioactive compounds responsible for the functional characteristics of fruits and their sub-products. Buniowska et al., (2020) [38] used plate heat exchangers for the thermal treatment of a drink based on exotic fruit juices; the treatment was at 60 °C, a lower temperature than traditional industry processes that pasteurize beverages at 88–99 °C. In this article, the authors found that drinks subjected to conventional heat treatments retained a high level of their antioxidant properties.

Among the conventional heating techniques used for fruit preservation, some are more modern, such as UHT, HPTP and HPP. These treatments are very fast and, therefore, afford the sterilization of the fruits with minimum losses of their sensory characteristics and functional properties.

Hulle et al. (2017) [10] explored how high-pressure thermal processing (HPTP) and high-pressure processing (HPP) influenced the quality characteristics of an Aloe vera–lychee mixed beverage. High-pressure thermal processing (HPTP) combines high pressure and heating, and HPP is a new technology that submits fruits to high hydrostatic pressures. Both technologies have proved to be effective in inactivating deteriorated microorganisms, extending the shelf life of foodstuff and, thereby, preserving desirable functional properties. Although in one study, the enzyme activity and the microbial population was affected after thermal treatments of HPTP and HPP, the authors reported that the quality attributes of the mixed drinks, such as physical–chemical, nutritional, and sensory characteristics, were minimally affected.

Unlike contemporary methods, certain articles cited in this review employed the conventional approach of sun drying or oven drying. For instance, Takahashi et al. (2018) [42] investigated the impact of solar and oven drying processes on the physicochemical characteristics of an economically significant pepper variety known as "hihatsumodoki". Their research aimed to identify optimal conditions that would preserve the pepper's pungency and antioxidant properties, while simultaneously achieving a sufficiently low water-activity level to inhibit microbial growth and spoilage.

Sun drying is one of the methods of fruit preservation that have been practiced for centuries. The direct or indirect use of the sun, which is renewable and low-cost, favors farmers that harvest and process in small quantities. Oven-drying is efficient as it combines the factors of heat, a low humidity and air flow, ideal for drying of fruit. However, the use of oven drying needs energy sources. When the authors compared drying in the sun with drying in an oven, they concluded that, during drying using solar radiation, the relative weights of the fruits reduced after 18 h of drying. On the other hand, the authors observed that increasing the drying temperature in the oven resulted in a reduction in the drying time, and the desired dry mass was reached in 24, 6 and 4 h at 50, 70 and 90 °C, respectively. Similar trends were exhibited in water-activity (aw) values. However, for the optimal production of spices, suitable for long-term storage, the best result was obtained when the samples were dried in an oven at 70 °C for 6 h, as they retained their functional value, piperine content, and antioxidant properties, in addition also to it having a better economic viability.

3.4. Non-Conventional Thermal Processing

Table 6 lists some articles describing the applications of conventional and non-conventional thermal processing treatments, such as microwave, ultrasound, ohmic heating, osmotic distillation, nanofluid technology, electric field (EF), and others [8,9,14,18,45,48–50]. Among these papers, a lot of fruits and sub-products obtained from their processing were studied, such as concentrated blood-orange juice, papaya pulp from ripe papaya (*C. papaya* L.), watermelon juice, dried key-lime juice, fruit shells of *Camellia oleifera*, compounds from fiber-rich by-products, and others.

Non-conventional thermal processing has been a promising avenue in fruit processing and can improve their rheological properties (viscosity), physicochemical properties (total soluble solids (TSS), titrable acidity, ascorbic acid, and total phenolic content), and other properties such as microbial characterization and antioxidant activities.

Cassano et al. (2014) [50] evaluated the effect of the solids concentration (155–700 g/kg at 20–70 °C) on the rheological properties of orange juices by using a strain-controlled rheometer. The fresh juice exhibited a pseudoplastic flow behavior. On the other hand, ultrafiltered juice and concentrated juices showed Newtonian behavior. The presence of residual pulp in the fresh juice can explain the results reported by the authors.

In addition, Gomathy et al. (2015) [49] applied ohmic heating as a non-conventional thermal processing treatment to papaya pulp, which can be considered a successful substitute for the pasteurization of this product. Papaya pulp's rheological behavior was non-Newtonian and pseudoplastic, with yield stress by the Herschel–Bulkley model (R^2 = 0.99). The fresh pulp's lower flow-behavior index values, when compared to those of the ohmic heated pulp, suggested that the apparent viscosity would grow more quickly under higher shear rates.

The alumina–water nanofluid processing of watermelon juice at high temperatures (75, 80, and 85 °C) for a brief period of time were studied by Jafari et al. (2017) [48]. Lycopene and vitamin C concentrations could be maintained after thermal processing using 0.2 and 4% nanofluids at 75 °C for 15 s. The pH and TSS indices of thermally treated watermelon juices do not significantly correlate with the heating media. The results showed that lycopene, vitamin C, and the color retention in the final product were all higher after processing the watermelon juice with alumina nanofluids compared to common thermal processing using water.

The electric field (EF) system described in the study reported by Altemimi et al. (2018) is one potential alternative technology, and showed superiority to heat pasteurization in terms of preserving the antioxidant activity, ascorbic acid, and total phenolic content of dried lime juice [18]. The healthful qualities of fruit juice can be enhanced during pasteurization to provide a product with a better retail value than one produced using conventional thermal processing. Furthermore, the results exhibited that neither the fresh-juice control samples nor all samples subjected to the electric-field (EF) system showed the growth of coliform bacteria, yeast, or mold.

Many studies conducted on specific fruits and vegetables have demonstrated that some alterations brought on by ultrasound involve a reduction in viscosity [14]. Cavitation processes alter their polysaccharide structures, which affects their viscosity by reducing particle sizes and molecular weights.

Li et al. (2022) [8] investigated an ultrasound technique, aiming to improve the physicochemical characteristics of betalain microcapsules. Under a low-intensity ultrasonic treatment (200 W, 5 min), the onset temperature and free-radical scavenging of betalain microcapsules rose by 1.6 °C and 12.24%, respectively, in comparison to the control sample. This rise might have been brought on by interactions between maltodextrin and the betalains, brought about by ultrasonification (as evidenced by FT-IR). Consequently, a low-intensity ultrasonic procedure can be employed for microencapsulation to increase betalains' stability and, therefore, broaden their scope of use in the realm of heat-processed foods.

Different drying techniques and treatment parameters for all material types can be optimized in order to improve their yields and process qualities. Thus, in order to optimize and model the drying process and selected physical attributes of slices of ultrasound-treated kiwi fruits before microwave drying, response surface methodology (RSM) was used Kaveh et al. (2022) [9]. Three independent factors were investigated: the ultrasonic pretreatment time, sample thickness and microwave power. According to the obtained results, its drying time decreased when the microwave power and ultrasound pretreatment duration were increased, along with its thickness. Furthermore, reducing the microwave power and sample thickness and lengthening the treatment period reduced shrinkage and changed its color.

3.5. Perspectives and Future Trends

Food processing is a set of unit operations to convert unprocessed foods into foods that have an extended shelf life. These procedures allow storage, which eliminates or reduces the time or effort devoted to cooking procedures to increase consumption. The highest-quality foods that have the highest demand are also very perishable. Luckily, using current technology wisely can preserve most perishable foods. By successfully applying commercially available food preservation technologies, it is possible to increase the availability of perishable foods. Despite the increasing demand for new processed products, the fundamentals of food processing remain the same for sustained availability in times of shortage. Processed food industries are struggling to meet consumer expectations for the manufacture of nutritious, enjoyable, convenient, safe, easily available, and affordable food of the highest quality.

The contemporary food industry is dedicated to developing products that enhance the safety of modern food consumption. Food processing procedures play a pivotal role in altering the chemical degradation, release, and bioavailability of bioactive components within food items, thereby influencing their biological activity. Traditional food processing methods like pasteurization, sterilization, cooking, and dehydration can impact the stability, bioavailability, and bioactivity of these components. More recently, the effects of emerging processing technologies, such as ultrasound, pulsed electric field, high hydrostatic pressure, and other non-thermal approaches, have also come under scrutiny. Some authors suggest that these innovative technologies may eventually compete with traditional pasteurization methods, as they can circumvent the detrimental effects of thermal degradation on the nutritional and sensory qualities of food products. These non-thermal technologies operate at ambient or sublethal temperatures, minimizing damage to temperature-sensitive food components.

Among the most relevant non-thermal technologies are high-pressure processing, pulsed-electric-field treatment, ultrasound, and cold plasma technologies. These non-conventional methods have the potential to enhance the sensory and nutritional characteristics of food products when compared to conventional processing techniques.

4. Conclusions

The conventional and non-conventional thermal processing of food has been widely used in different applications, and the existence of cooperation between established groups, countries and institutions in its research has been observed. Among the main countries addressing this topic are China, USA, Brazil, India and Spain.

The findings concerning the involvement of various authors in research on thermal food processing reveal that the collaboration clusters primarily consisted of Chinese and American researchers. As expected, the majority of studies on thermal food processing were conducted by scholars in the fields of food science and technology, applied chemistry, and chemical engineering.

The proportion of total papers focusing on the thermal processing of fruit and the effect of some of its properties was reduced from 794 papers to 35, approximately 4.4%. These 35 articles explained the application of different thermal processes, and a total of 21 addressed the use of conventional thermal treatments. A summary discussion of some of the conventional thermal processing techniques was applied in in natura fruits and in their products, such as flours, juices, pulps, beverages, powders, husks, and almonds.

Non-conventional thermal processing has been promising in fruit processing and can improve their rheological properties (viscosity), physicochemical properties (total soluble solids (TSS), titratable acidity, ascorbic acid, total phenolics) and other properties, such as their microbial characterizations and antioxidant activities. While conventional thermal processing is still being studied for fruit applications, the utilization of emerging or non-conventional technologies has the potential to enhance the sensory and nutritional characteristics of these products in comparison to traditional methods. It is expected that these innovations have the potential to have a significant impact on the food industry in the future.

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