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Technological Intensification of the Edible Film-Making Process Using Bibliometric Analysis

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Abstract

Edible film is a material that can be an alternative solution to environmental problems caused by plastic food waste. The edible film can be produced from a natural material, like starch. With the support of adding natural components such as plant extracts which contain high levels of antioxidants and polyphenols, the quality of edible film can be improved. However, changing natural polymers requires large costs, due to the use of large amounts of energy and inefficient processing times. Therefore, technological intensification through the development and improvement of methods and equipment is needed, to produce new designs that are more effective and efficient in increasing production. This research aims to examine the technological intensification of edible film manufacturing which has been carried out by several researchers. Study through bibliometric analysis with VosViewer. The database is taken from Scopus with the keyword "Edible Film" from searches from 2018 to 2024, subject areas limited to chemistry, materials science, chemical engineering, biochemistry, and environmental science. The results obtained were 141 articles related to the technological intensification of the edible film manufacturing process. This intensification has fulfilled the principles of process intensification starting from the domain development of the energy, structure, synergy, and time.

Keywords: Bibliometric analysis, Edible film, Intensification, VosViewer

1. Introduction

Edible film is a polymer material product that can be an alternative in solving environmental problems. Specifically, edible film is a bioplastic material that can be consumed [1]. Apart from being a substitute for packaging material, edible film must also be able to extend the shelf life of the packaged material, protect food from microbial contamination, and improve the properties of packaged food without changing the taste and aroma [2]. The existence of this product has encouraged scientists to compete in research and publish their findings in the form of scientific publications.

There have been many publications of research results related to edible films. Even before 2018, there were several publications discussing edible film products or food packaging, including Han [3], Azeredo [4], and Galus & Kadzińska [5]. Han [3] explains many things about edible film, starting from its main function for food packaging, additional functions, raw materials, formation mechanisms, and expected characterization standards. Apart from that, he also said there is a need for further research regarding optimizing properties, evaluating processes, and the feasibility of consuming edible film. Meanwhile, innovations related to edible film process technology have been presented by Azeredo [4]. He said there had been efforts to use nano-sized fillers (such as clay, and silica) by researchers to produce

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nanocomposites in food packaging. Nano filler can strengthen mechanical properties and add functions such as antimicrobial, enzyme immobilization, and so on. However, the level of safety of using food packaging materials is questionable, especially regarding its toxicological effects. Therefore, the use of nanofiller is not the best solution for the edible film manufacturing process technology. This is different from Galus & Kadzińska [5] who wrote about emulsification's application in making edible film. According to him, food packaging made from a mixture of various components, such as hydrocolloids and lipids, can produce film products that are functionally better than those made from just one component. This research has become a reference for several researchers to make edible films by combining various organic materials. Apart from these three publications, there are many other publications from various research results on the same product topic from various scientific disciplines, including social sciences, mathematics, health, energy, chemistry, chemical engineering, materials engineering, and so on. With bibliometric analysis, research development mapping on edible films can be carried out. The statistical methods applied in bibliometric analysis have analyzed the metadata available in publication databases related to edible films developed by many institutions in the world, both those that can be accessed for free and those that are subscribed. Bibliometric analysis can be used to determine the development of certain research topics [6], including the topic of edible films. George et al. [7] and Omoregbe et al. [8] suggest that bibliometric analysis uses quantitative data to track, identify and evaluate research performance. The aim is to understand research trends in a particular field through publications published from various countries in the world. Bibliometric analysis uses scientific databases (such as Scopus and Web of Science) and software (such as VosViewer, Citespace, Leximancer, and so on). With the database and software used, this analysis can show the scientific contribution of edible film research results; performance and mapping of edible film research; as well as a network of collaborations between researchers, organizations, and countries researching edible films in the same period. Collecting and obtaining accurate information through bibliometric analysis can be a basis for scientists in determining the direction and focus of research in the field of edible film technology. Bibliometric analysis can be useful as a basis for further research, and preventing similar research from occurring [9].

The bibliometric analysis on the topic of edible film in this paper begins with a database from Scopus, then from the publication data obtained, it is then sorted regarding the intensification of the Edible Film process and saved in RIS format. RIS is a bibliographic database with citation programs, one of which is the Mendeley program [10]. In the analysis, many applications can be used, but one that is quite well-known and tested is VosViewer (Similarity Visualization). VosViewer in this research was used to map research related to the intensification process in making edible films. The intensification of the edible film process can be seen from 4 (four) domains, namely the structural (spatial) domain which focuses on structured environments, the energy (thermodynamics) domain which focuses on alternative forms and energy transfer mechanisms, the synergy (functional) domain which focuses on integration functions/stages, and time domain which focuses on time and process dynamics.

In the process of making an edible film, some stages are possible to carry out, namely modifying the structure of the raw material, mixing the raw material with plant extracts, and printing the edible film. The raw material generally used is starch. Apart from that, the presence of other important components in edible films, such as phenolics, is also necessary because they can act as bioactive and a source of additional nutrition for consumers. Therefore, many edible film products currently being created include extracts of various types of plants, especially those containing high phenolic content. The challenges in creating edible film products are related to mechanical properties and hydrophilic properties. These two properties can be overcome through process engineering techniques and nanotechnology [11]. Therefore, the main technological developments related to the process of making edible films are mostly directed toward the field of nanotechnology, including processes that can change the raw materials of edible films (for example starch) into nano-sized such as ultrasonication processes, blending, and so on.

Natural starch cannot be used directly as packaging plastic, because it has high hydrophilic properties. With increasingly advanced technological developments, starch can have its chemical structure modified so that its characteristics change so that it can be turned into an alternative product to replace synthetic plastic. Most of the edible films that have been created still have weaknesses in their mechanical properties, which are easily brittle (less strong), low elongation, and high water vapor permeability because they have weak hydrogen bonds [12]. To correct this deficiency, a structural modification is required.

Starch structure modification techniques can be carried out using physics, chemistry, or a combination of both [13]. The most widely used method is group substitution, known as the acetylation method. This method is currently still being developed so that the process does not take too long, is energy-intensive, and is more economical. Hong et al. [14] stated that starch modified using conventional methods has weaknesses in terms of cost, excessive use of chemicals, and is inefficient in terms of time. Dwi et al. [15] stated that the long time for the acetylation process is due to the strong molecular bonds in the starch, which are not easily penetrated by acetylation reagents, so the reaction only occurs on the surface of the starch and requires a long time. However, the acetylation method has been able to improve the hydrophobic properties of starch and increase its biodegradation ability [16] [17]. Therefore, this method continues to be developed by studying the factors that influence the process. One of the studies that had a big influence on the development of the acetylation process was: a study of the effect of differences in catalyst concentration on the acetylation reaction by Halal et al. [18].

In general, converting natural polymers, whether only as additional materials or as main raw materials, still requires large costs, due to the use of a lot of energy and inefficient processing times, especially for development to a production scale that is still not profitable for producers. Therefore, intensification of process technology for edible film through the development and improvement of methods and equipment must continue to be carried out, to produce new designs that are more effective and efficient in increasing production results.

2. Experimental

A search for publication data was carried out on the Scopus website with the keyword "Edible Film" with a search period from 2018 to 2024. The results found that there were 1038 articles in the subject areas: chemistry, material science, chemical engineering, biochemistry, and environmental science. The initial year limit was chosen, namely 2018, the initial year for the increase in publications related to edible films published on Scopus based on subject areas that are close to specific topics related to the intensification of the process of making edible films. The findings show that the number of research publications is quite large and to analyze them it is necessary to study them further, at least from the titles and abstracts of the articles. From checking the authors, it was found that 141 articles matched the specific topic to be analyzed. Bibliometric analysis was carried out using VosViewer based on text mining and assisted by the Mendeley application whose metadata is stored in RIS form. Text mining analysis is an analysis of the occurrence of each mapped word. Meanwhile, the calculation method used uses the full counting method. The full counting method considers the number of occurrences of each word. Several important articles in each cluster were analyzed and their contents were reviewed to then be used as sources for literature studies. A literature review reviewing the intensification of the edible film manufacturing process in terms of energy, structure, synergy, and time.

3. Results and Discussion

3.1. Bibliometric Analysis Results

The distribution of publication data on the Edible Film topic in Scopus for the period 2018 to 2024 is as follows:

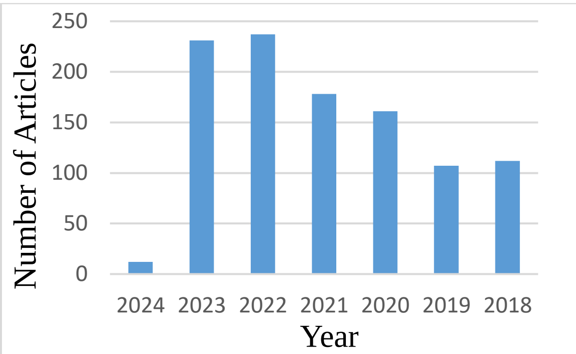

Fig. 1. Number of publications on the topic of edible films from 2018-2024.

The results of this distribution show that there is an increase in publications on the topic of edible films from year to year, which indicates that this research topic is still being researched by researchers from all over the world until now, with most research based on Scopus data, namely from China with a total of 193 publications. Many of these publications were published in hydrocolloid food journal. The results of this analysis are slightly different from Kusuma, et al. [19] research because the focus of the study in this research is related to process technology intensification. In Kusuma, et al [19] research, China produced 323 publications about edible films with the most journal sources from the international journal of biological macromolecules in 2018-2022, without any subject area restrictions.

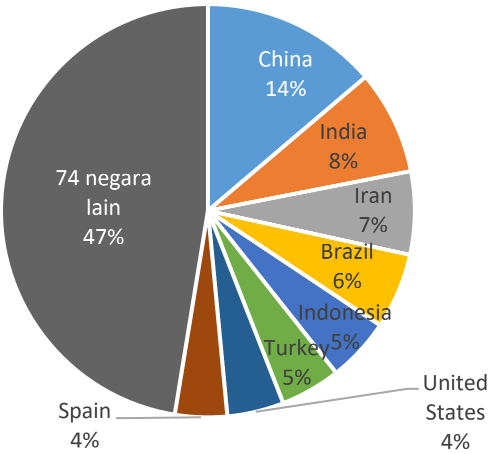

Fig. 2. Percentage of the number of publications on the topic of Edible Film from various countries from 2018-2024 with subject area restrictions.

In fact, in 2024 there will be 12 publications recorded from data records in December 2023. The increase in the number of research on the process engineering of edible film is due to continuous intensification carried out by scientists to increase the productivity of edible film. Colussi et al. [12] said that research related to starch modification for edible film production often provides different results and different interpretations. The key to the readiness of edible film application depends on the modification process of starch as a raw material. However, from these studies, the author obtained around 141 articles which can be used as references for intensifying the process of making edible films and then analyzing them with the VosViewer application.

The results of text mining analysis with the VosViewer application using the full counting method obtained 424 words. By setting the minimum word limit to 3 words, 42 words were obtained which were grouped into 9 clusters.

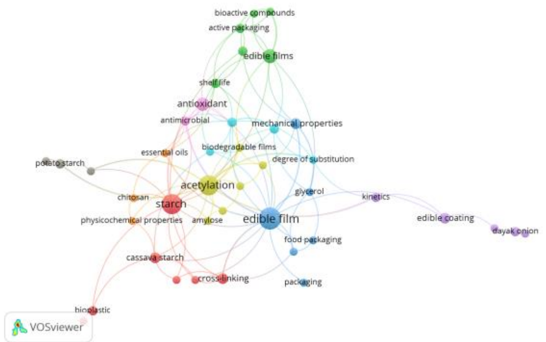

Fig. 3. VosViewer text mining analysis results using the full counting method.

The results of the analysis above show that there are groupings of words (clusters) that represent a particular research focus. Each cluster is presented with a different color. Bibliometric analysis of the image shows that there is a relationship between one study and another (characterized by a line connecting the clusters). These results show that starch can be a raw material for bioplastics in general and can also be used for non-active edible film packaging. The starch modification method that is widely used is acetylation which is marked in yellow, apart from crosslinking which is marked in red. After going through the acetylation process, modified starch can be made into biodegradable film. If essential oils or bioactive components (antimicrobial and antioxidant substances) are added to make a biodegradable film, it has the potential to become an edible film which has a role as active packaging. This increasing role, which is currently being developed and researched further, is also clearly demonstrated through VosViewer in the overlay visualization section. Even though conclusions have been obtained, this article only represents publications on Scopus. The development of research into the intensification of the process of making edible films as a whole is not necessarily limited to what is presented because more published data could be found in different bibliographic databases, such as Web of Science, Dimensions, Lens, and PubMed.

3.2. The Study Results of Technological Intensification of the Edible Film-Making Process

The publications that have been analyzed provide information about the intensification of the edible film manufacturing process, with its 4 domains that need to be handled simultaneously. The four domains are shown in Table 1.

Table 1. Four (4) Domains of Edible Film-Making Process Intensification

Domain	Main focus	Process intensification concept	Motivation
Energy	Alternative forms and transfer mechanisms of energy	Sound energy with ultrasonication and activation energy	• Decreased fluid resistance • Application of ultrasonication intensity to minimize damage to the amylose structure in starch • Minimal energy use • Improved physical and mechanical properties of edible film
Structural	Structured environment	Micro and nanoparticle materials, catalyst replacement	• Increase in reaction surface area • Increased acetylation reaction speed with minimum energy • Increased mass transfer rate through reduced solid diffusion resistance • Low production cost with less use of chemicals
Synergy	Integration of functions	Combination of constituent materials, process combination, and determination of operating conditions	• Synergize several processes and operating conditions • Synergizing interactions between materials • Increased DS value and acetyl level • Increased nutritional value
Time	Timing of the events	Time efficiency and dynamic energy supply	• Improved energy efficiency • Dynamic use of sound energy • Prevention of complex reactions

The intensification of process technology in making edible film that has been carried out by researchers based on these publications is aimed at developing process designs that are more effective and superior, in terms of safety, operating costs, energy use, and so on. Apart from that, it is also aimed at increasing production results through improving methods and/or increasing production factors. Intensification has been carried out starting from the initial stage, namely at the starch structure modification stage. This is because natural starch cannot be used directly for making edible films because of its high hydrophilic properties. Previous researchers produced edible films that were brittle and had low durability when made from natural starch without modification. For this reason, process modifications are very necessary, including improving the chemical, physical, and mechanical properties of edible film.

One effort to intensify the process for edible film is the development of nanotechnology. Nanotechnology has triggered the development of edible film products, not only in quantity but also in terms of high quality in terms of chemical, physical, and mechanical characteristics. Targets for improving the characteristics of edible films in the food sector include texture, taste, color, solubility, shelf life stability, nutritional content, absorption, and availability of bioactive compounds. With nanotechnology, the process time for edible film production is getting shorter, from previously 5 hours or more, to 1 to 2.5 hours [20]. The small particle size causes the surface area to be larger, thus potentially increasing solubility [21]. In this case, the solubility of starch in the solvent during the process of modifying the starch structure. Small particle sizes can also produce new physicochemical properties of starch, such as large surface area, reactivity, and color compared to other materials with larger sizes [22]. These new properties can save the use of raw materials, speed up the process, and increase precision and accuracy [23]. The application of nanotechnology innovation to the process of making edible film has been able to control the size and shape of molecules so that the physical, chemical, and mechanical properties change from their original properties and also edible film products have better quality. The edible film made from natural nano ingredients can cover food ingredients better, so it can protect food products from microbes, contamination, oxidation, and food spoilage [24] [25].

Researchers have made many efforts to intensify the process of making edible films, one of which is by combining the acetylation process with a process that uses a sonicator (ultrasonication). Dwi et al. [15] modified the acetylation method discovered by Colussi et al. [12] by applying an ultrasonication process before the acetylation stage. Ultrasonication can improve reaction efficiency through the formation of new pores and reaction surfaces. Ultrasonication can create holes in starch granules so that the reaction surface area increases and the acetylation process becomes more effective and efficient [26] [27] [28]. When associated with changes in starch characteristics, the ultrasonication process has different specific impacts, depending on the ultrasonication intensity used. Zhang et al. [29] stated that applying high-intensity ultrasonication for 10 minutes to starch can improve starch structure, mechanical properties, and water resistance and reduce Water Vapor Permeability (WVP). This is related to the particle size obtained as a result of ultrasonication. Ultrasonication can change the size of starch particles from micro to nano-sized [30]. Another result is the acetylation process using high-energy ultrasonication by Dwi et al which requires a shorter time than Colussi et al, namely 90 minutes. The time acceleration is caused by a decrease in fluid resistance due to the effect of using sound energy from the ultrasonication process. As a result of applying the ultrasonication process, the Degree of Substitution (DS) value can reach 2.68 times higher than Colussi et al research with the same starch material. The degree of substitution is a measure of the number of acetyl groups (% acetyl) that are substituted in natural starch. DS determines the characteristics of acetate starch (modified starch) as a parameter to measure the success of making the final product, namely edible film. Increasing DS can improve the mechanical properties of bioplastic raw materials, especially the elongation and tensile strength values [31]. Another discovery is from Liu et al. [32] who found the influence of high (70% setting or power 560 W/cm^2), medium (40% setting or power 320 W/cm^2), and low (30% setting or power 240 W/cm^2) ultrasonication intensity on starch characteristics. This researcher found damage to the amylose structure in starch due to high-intensity ultrasonication treatment and according to him the appropriate intensity for ultrasonication treatment on starch is medium intensity (setting 40%). Appropriate ultrasonication intensity can reduce aggregation so that uniformity in each part of the edible film is more even. During the ultrasonication process, more reaction centers appear with the formation of more chemical bonds [33]. Wang et al. [34] in their research has produced a maximum Edible Film elongation value of up to 142.38 ± 5.27% at an ultrasonication intensity of 400W. This increase is 125% higher compared to Edible Film which was not treated with ultrasonication. The reduction in particle size due to ultrasonication promotes the formation of new chemical bonds that contribute to increased elongation of the edible film.

Apart from reducing raw materials from the start of the process which can reduce solid diffusion resistance and ultrasonication which can lead to nanotechnology, intensification of the Edible Film process technology is also carried out by changing the catalyst in the acetylation process. Trela et al. [35] used a base catalyst with a high concentration, namely 50% NaOH. Replacing the catalyst, which generally uses an acid and then changes it to a base, can help the hydration process and prevent damage to the starch structure by conditioning the alkaline pH. Before 2018, the acetylation process generally used excessive amounts of 2 acetylation reagents, namely acetic acid and acetic anhydride. However, by using high concentrations of NaOH as a catalyst, we can save on chemical use because we only use one reagent, namely acetic anhydride. Economically, this modification is more profitable for the production of edible film because the process stage that requires large costs is generally the starch modification stage. Apart from saving, the use of acetylation reagents from acetic acid is no longer recommended (needs to be avoided). Acetic acid reagents can make it easier for water to enter the resulting product film. Water will weaken starch hydrogen bonds and facilitate the reduction of amylopectin in starch, so that modified starch and edible films are easily soluble in water [36]. With the help of a catalyst, more acetyl can enter the starch structure, so that the target DS >1 can be fulfilled. This target is the best DS value standard for edible film products. The large number of acetyl groups that enter the starch structure can inhibit the formation of bonds between starch molecules, and cause the gelatinization process to occur more quickly with less energy requirements. The mechanism for the entry of acetyl groups is the same as the chain growth mechanism in polymers in general. This mechanism produces less polymer, but a higher molecular weight. As stated by Al-Sharify et al. [37], the growth of polymer chains can increase viscosity so that gel can be achieved more quickly.

Gelatinization temperature has a significant influence on the biodegradation characteristics and mechanical properties of edible films [38]. For the process of forming edible films, low gelatinization temperatures provide an advantage because gel formation can be carried out at low temperatures. In addition, due to the substitution of the catalyst with NaOH, starch molecule rearrangement occurs, new crystal structures are formed, the mobility of starch molecules increases, and recrystallization is inhibited [39]. Thus, the impact is very beneficial in the edible film formation process because it makes it easier for the modified starch functional groups to react with other constituent materials such as CMC, chitosan, and plasticizer, or in other words, there is an increase of chemical properties of starch compared to before modification.

Apart from that, the current intensification of edible film is also aimed at increasing the function of the product, namely as bioactive food packaging. This can be done by adding active additives or active components from plant extracts which can increase the cohesive force with the edible film polymer chain, resulting in a change in the structure of the film due to the formation of new chemical bonds from the reaction of the two materials [40]. Several starch properties, such as chemical structure, thermal properties, and mechanical properties are influenced by the addition of active components [41]. Several researchers such as Zaman et al. [42] and Fan et al. [43] said that the addition of plant extracts containing polyphenols can increase the thickness of edible film. Increasing thickness provides benefits in protecting packaged food ingredients because there is an increase in the mechanical properties (in this case tensile strength and elongation) of edible film. Improved properties can also occur due to interactions between polyphenolic compounds in plant extracts and the ingredients of edible films [44]. However, in several studies from the publications that have been analyzed, some say something different, the addition of polyphenolic compounds from plant extracts can increase tensile strength but has an impact on reducing elongation. One of the researchers who suggested this was Jridi et al. [45] dan Aziz et al. [46]. The addition of excessive amounts of plant extracts can disrupt the homogeneity of the film, causing the elongation value to decrease [47]. Therefore, the addition of plasticizers is still needed to overcome the decrease in mechanical properties. Improvements in edible film flexibility and structural changes due to the addition of extracts can be reduced by reducing interactions between extract molecules and edible film raw materials [48] [49]. Based on the results of these studies, selecting extracts taking into account the amount of polyphenolic compounds is also the main key to improving the mechanical properties of edible film, although elongation can be assisted by adding plasticizers. The synergy between polyphenolic compounds and plasticizers in modified starch can produce edible films with good characteristics. The addition of active components also has a positive impact on edible films. Improvement and enhancement of food quality (pH, color, and nutrition), safety of packaged food during storage, and inhibition of pathogen growth (as measured by the diameter of the inhibition zone) can be achieved by adding plant extracts [50] [51] [52] [53].

4. Conclusions

Bibliometric analysis of 141 publications regarding technological intensification of the edible film manufacturing process with VosViewer showed that intensification by researchers had been carried out in various ways, starting from starch modification process engineering, reducing the use of chemicals, replacing catalysts, synergizing between processes and combining the main process materials with active components and plasticizers. This intensification can result in the design of new methods that are more efficient in terms of processing time, and increase the quantity and quality of edible film. All of these have been able to fulfill the principles of process intensification in terms of (domains) energy, structure, synergy, and time. The application of the concept of process intensification in the manufacture of edible film from the energy domain includes: changing the type and concentration of catalyst, as well as using the ultrasonication process and determining its intensity; the structural domain includes: reducing the use of chemicals and establishing the concept of nanotechnology; the synergy domain includes: combination of ingredients that make up edible film, combination of processes, especially acetylation and ultrasonication, as well as setting several operating conditions; time domain through time efficiency and dynamic energy supply.

5. Conflicts of interest

The authors declare that there is no conflict of interest in anything written in this publication

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