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Agro Biopolymer: A Sustainable Future of Agriculture – State of Art Review

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***Abstract* – Due to the rising demand for food and feed, agricultural waste increases, while plastic pollution increases due to hostile human activities. The sustainable way to utilize agricultural waste and promote the bioeconomy concept is to produce an alternative product of plastic, i.e., 'bioplastic'. This paper used different keywords to perform the bibliometric analysis of the scientific publication related to bioplastic, agricultural waste, and sustainability. Remarkably, results show the increasing research interest in bioplastic with the key developing trends in sustainable bioplastic production, agriculture waste management, biopolymer, and biological processes. The identified developing trends can be used for further research to create a sustainable agricultural sector and produce higher added-value products. Moreover, this study discovered that the agro-biopolymer area needs more focus on sustainable development considering the economic, social, and environmental dimensions.**

***Keywords* – Agricultural waste, bibliometric analysis, bioplastic, biopolymer, research gap**

1. INTRODUCTION

The worldwide population is increasing day by day; therefore, the production and distribution of food have increased to fulfil the need of the continuously growing population. The agency of food and feed activities were established in 1945 by the United Nations, known as the 'Food and Agricultural Organization (FAO)'. Agriculture has become more productive worldwide after the FAO was introduced [1]. The agro-industry is one of the significant waste production sectors, including a vast amount of production processing waste [2]. The agricultural sector is facing a diverse problem due to over-consumption of land, forage, and food production [3]. The excessive use of resources and waste generation can cause substandard environmental conditions. Such aspects may disrupt environmental stability on a global scale [4].

Firstly, modern agricultural technology has become more adventitious for increasing crop production. However, modern technology has an adverse effect and creates long-lasting footprints on the environmental, social, and economic sectors [5]. Secondly, waste generation by agricultural activities has become a significant problem. According to [6], humans generate 150 billion metric tons of agricultural waste yearly through intensive farming, harvesting, cultivation, and industrial processes. Unfortunately, this waste resolves by random burning or landfilling activities, which leads to environmental pollution and inappropriate use of resources [7].

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Over the past seven decades from the 1950s [8], plastic demand has increased because it is lightweight, affordable, varied, and readily available. The production of plastic causes a significant environmental impact, considering climate change, greenhouse gas emissions, and marine ecosystems. Plastic pollution affects socio-economic and ecological issues as well [9]. Fossil fuel is a primary resource used in the production of plastic, leading to greenhouse emissions at each stage of the life cycle life cycle stage from extraction to end-of-life [10].

In this regard, the bioeconomy can be one of the ideal solutions to resolve agricultural waste concerns while tackling the plastic pollution problem. The bioeconomy allows valorizing agricultural waste into value-added products using bioconversion processes. Agro-industrial waste includes significant grain, dairy, and food waste. Only a tiny portion of the waste is used as animal feed, manure, and other products. Most of the waste is unutilized, which can be a potential source in the production of bioplastics [11]. Agricultural waste includes livestock, agro-industrial, and aquacultural waste [12].

The modern approach to bioeconomy also involves many technological innovations, for example, large-scale biotechnology applications. New opportunities can be established using modern biotechnology to produce bioplastics from bioresources. The bioeconomy also ensures that the use of bioresources in the bioeconomy is sustainable, efficient, and economical [13]. Bioeconomy improves resource efficiency and waste management streams by providing a replacement for fossil fuel-based resources. It helps to reduce the production cost by promoting agricultural feedstock as a substrate to produce bioplastics [14].

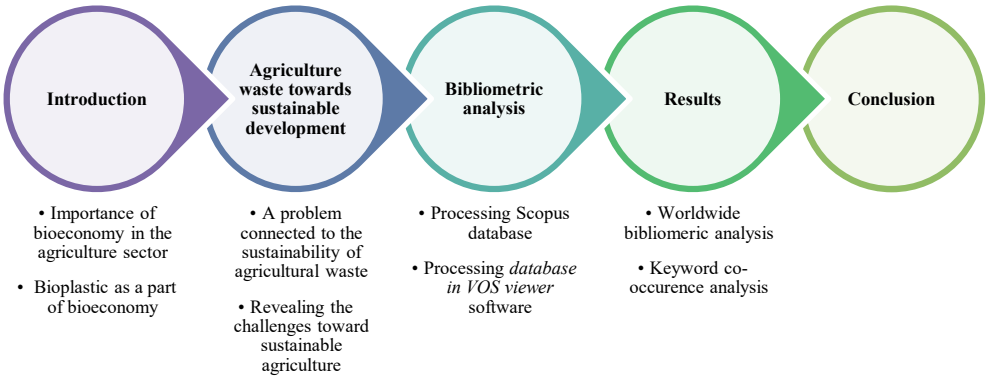

Fig. 1. The overall structure of the study.

This study applies the bibliometric analysis methodology and reviews agriculture waste and bioplastics, considering the sustainable development goals. The overall structure of the study is briefly described in Fig. 1.

2. AGRICULTURAL WASTE TOWARDS SUSTAINABLE DEVELOPMENT

2.1. The unsustainability of agricultural waste management

Modern agricultural practices severely affect the environment by releasing polluting compounds (such as heavy metals, excess fertilizers, and chemical substances) into the

environment, including soil, surface, and groundwater. These compounds affect crop productivity, human health, and soil and water quality. In addition, chemical substances can cause human diseases through food and water contamination [3]. Due to unfavourable conditions of the environment, crop productivity can decrease by 30–70 % [15]. Farmers are the first to be affected by this uncertainty. The depletion in crop production causes lower crop yields, which leads to a decline in income for the farmers. Moreover, occupational injury, illness, and fatalities can also occur to workers and local communities [16].

In the agriculture sector, crops are long-term investments. Food waste covers the most significant part of the agricultural waste, which can cause a loss of economic value for the agriculture business entities. Globally, food loss and waste value are estimated at one trillion US dollars. Food crops are the primary source of income in some regions, and the seasonal fluctuation in crop prices can affect the international market. Consequently, a significant loss in agricultural product availability arises and affects the overall income of associated agricultural entities [17].

Regarding agricultural waste management, many scientific studies have addressed the three pillars of sustainability, i.e., environmental, social, and economical. Bhuvaneshwari *et al*. address the issue of the burning of agricultural waste in India. Crop residue burning is a major environmental issue worldwide that can cause human health issues and global warming, which leads to climate change. Moreover, burning agricultural residues involves several other sectors, including the environment, agriculture, economy, society, education, and energy. However, the government's efforts toward educational and societal development are insufficient. The burning issue and related impacts can be solved if proper education and awareness are raised among farmers and society [18].

Scarlat *et al*. addressed environmental and economic concerns associated with removing agricultural crop residues, reducing the soil quality, loss of organic matter, soil carbon, and nutrient content, and increasing erosion. The inappropriate disposal of agricultural biomass can cause severe effects such as crop farming practices, soil fertility, moisture, and climate conditions (wind and precipitation) [19], leading to a decline in harvested crops and thus economic loss.

Sabiiti Elly reports concerns regarding the amount of waste generated by the agricultural sector. The increased demand for food leads to large agricultural waste production at various levels, including farmers, municipal, and urban areas. This untreated waste can cause human illness and affect the environment [20]. The improper disposal of agricultural waste can cause an impact on air quality by the emission of odorous substances such as ammonia and greenhouse gas emissions that cause climate change issues [21].

Several barriers are identified by Benyam *et al*. to implementing sustainability in the agricultural sector. The continuously growing farms and demand for food cause resource scarcity and extreme climate change. Modern farming techniques (such as fertilizer and pesticides) undermine the use of naturally derived crop nutrients [22].

The significant economic barrier to sustainability includes the complexity in the efficiency of the technology, lack of knowledge of the production technology, and technology cost limits to the socio-economic benefits for small-scale farmers. The social sustainability barriers are the farmer's lack of expertise in digital technologies, knowledge transfer issues varying the uptake of technologies, and extensive technology adoption that drives unemployment [22].

Agricultural biomass is a vast market for producing bioproducts. However, several barriers can affect the development of sustainability, for example: a) access to information on biomass market functions, b) insufficient knowledge about the benefits of energy efficiency, c) financing sources, d) market infrastructure, and e) agricultural, energy, & environmental policy development. Moreover, other significant concerns identified in developing the

agricultural biomass market include a lower possibility of selling biomass profitably, no systematic collection of biomasses, lack of interest in biomass, lack of transportation to supply biomass, and unawareness of the biomass concept [23].

The consequence of agricultural waste production reveals many potential steps that must be taken to prevent environmental impacts and promote the sustainable development of the agricultural sector. A tremendous amount of agricultural waste is produced every year. Still, current approaches to waste reduction are comparatively ineffective due to several barriers such as a lack of farmer's expertise in long-term planning considering sustainability aspects, inconsistent sustainability strategies, and lack of added value approaches. With this concern, the next chapter of this study introduces the approaches that can contribute to resolving a global challenge and establishing sustainable agriculture.

2.2. Resolving the global challenge toward sustainable agriculture

According to the global survey, the assessment of biomass value chains should consider the whole life cycle of a bioproduct from biomass production, pre-treatment, transport, and conversion techniques, to end of life. Several opportunities have been identified for the biomass market, considering economic development, job creation, improvement in production systems, sustainable development, and progress in the supply chains [24].

The transformation of the agricultural industry to circular practices has become a challenge for the industrial revolution. A recent study investigated a circular economy conceptual framework as a way forward to sustainability at the industrial level. The framework of sustainability focuses on the circular economy concept. This framework mainly consists of a) pillars of sustainability (economic, social, and environmental), b) key drivers (feedstock, low carbon product, life cycle, zero-emission, reduce, recycle, and reuse), and c) tools to evaluate and design circularity (material flow analysis, life cycle analysis, and eco-design), and d) the conceptual framework (production stages and integrated assessment methods). This strategic framework can establish sustainability at the industrial level [25].

Belaud *et al*. proposed an integrated approach by integrating big data and sustainability assessment to improve the supply chain design of the agricultural sector. Big data shows the digital and ecological transition for the valorization of agricultural waste. The agricultural by-product valorization is a challenging supply chain, including the operational stages (from biomass to waste disposal), transformation, upstream, and downstream processes. Also, the life cycle assessment methodology has been approached to analyse the impact and various sustainability indicators. However, this approach has a limitation that needs to be explored more: a) addition of specific data sources, methods, and visualization for economic and social areas to improve data inventories and assessment methods, b) the design models for energy, c) development of libraries, sources, and studies for agro-food process engineering, and d) the development of qualitative explanation systems for stakeholders [26].

Barros *et al*. presented a systematic approach to the input-output methodology for agricultural waste valorization. The input (i.e., fuel, water, energy, raw material, animal food, and seed), output (i.e., wastewater, emissions, grains, and agricultural waste), material, and energy flow in the agriculture sector. The input-output flows vary among the different alternatives, such as rural properties containing animal breeding, and the inputs include water, energy, animal food, and medicine. On farms for wheat, corn, and soybean crops, the inputs include water, fuel, seed, and fertilizers. Also, the techno-economic and life cycle analyses have been used to assess the environmental impact of an entire agriculture supply chain, including transportation, processing unknit, and agro-industrial processes. However, the life cycle sustainability assessment method is complex and time-consuming; therefore, limited approaches have been carried out for the sustainability assessment in the agricultural field.

Also, new circular business models need to be created considering the diversity of the circular agricultural economy [27].

A recent study presented an overview of the existing modelling tools to assess the environmental impacts of agricultural waste considering the circular economy concept and industrial ecology, life cycle thinking, and flow analysis. The study finds that life cycle thinking can be a promising tool to assess the effects of and evaluates circular economy characteristics. This study encourages scientists to use such strategies to solve waste problems. The study suggests that the circular economy development policies need in-depth investigation. The integrated approach for the circular economy should be studied more to find more strategies, i.e., suitable for all types of waste categories [28].

A vast amount of agricultural waste is produced yearly, and 50 % of raw materials are discarded without treatment. Amran *et al*. addressed the issue of agricultural waste valorization to improve economic and environmental sustainability. Also, the sustainable strategy in terms of applying green extraction technology. Agricultural waste valorization by using green extraction techniques can increase productivity, social acceptance, and economic stability. Universal problems such as waste management, environmental impacts of landfills, climate change, fossil fuel reduction, and sustainability issues for farm owners can be solved by implementing such strategies. However, this strategy still requires further development to integrate sustainability into the valorization system at the industrial level [29].

Cho *et al*. presented the potential use of biochemical processes to produce biochemicals. Biomass waste is inexpensive, readily available, and renewable. Also, accomplish the fossil fuel demand, manufacturing costs, and address environmental concerns. However, this study identified that conversion technologies need further research to produce competitive products [30]. Overall, the challenges and shortcomings of sustainable agriculture are broader than the already established solutions.

2.3. Agriculture waste to build agro-biopolymer

The industrial revolution in the agricultural sector needs to be implemented by imposing the “resource, recovery, and recycle” concept. The bioeconomy can better balance the environmental, economic, social, and technological aspects of agricultural resources. Besides, the bioeconomy encourages sustainable agricultural sector growth by utilizing resources, providing economic growth to resources, and establishing a balance between consumption and production demand [31].

The agricultural waste valorization pathway has become an evolving approach to producing biopolymers over the last few decades. The conversion of bioplastic from agricultural waste is a more focused area as it leads to sustainable development [32]. Bioplastics can be produced from food, grain, and food waste. Agricultural by-products and inedible food waste are significant sources of bioplastics such as potato peels, sugarcane bagasse, whey protein, eggshells, maize grain, paddy straw, barley straw, rice straw, wheat gluten, and soy protein [33], [34].

Bioplastic production can significantly increase sustainability in the agricultural sector in economic, social, and environmental aspects [14]. Table 1 provides a brief overview of various bioplastics and their versatile applications.

TABLE 1. BIOPLASTIC TYPES AND APPLICATIONS

Type of bioplastic	Example	Description	Application	Source
Aliphatic Polyesters	PLA, PHB, PHA	Include more resistant material, required syntenic biodegradation	Biomedical field, food packaging, film wrap, and utensils	[35]
Protein-based bioplastic	Casein bioplastic	Derived from dairy wastes like milk, wheat gluten, soy protein, and other protein resources	Casein film that extends the shelf life of food products	[36]
Starch-based bioplastic	TPS, Bio-PET	Covers 50% of the global bioplastic market, contain synthetic or natural starch extracts	Food packaging, hygiene products (toothpicks & food service ware)	[37]
Cellulose-based bioplastic	Cellulose acetate, methylcellulose	Derived from cellulose esters or derivatives, they contain glucose molecules	Used as an edible coating for several food items to increase shelf life, biomedical applications like tissue engineering, wound healing, & medical implants	[38]

Notes: PLA- Polylactic acid; PHB- Polyhydroxy butyrate; PHA- Polyhydroxy alkenoate; TPS- Thermoplastic Starch; Bio-PET- Bio-polyethylene terephthalate

3. BIBLIOMETRIC ANALYSIS

Bibliometric analysis is performed based on the Scopus database. Scopus is the largest abstract database and provides exhaustive coverage of scientific journals. Moreover, Scopus provides high-quality assurance of database highly recommended for research assessment, scientific evaluation, and research studies [39]. Bibliometric analysis by using the keyword co-occurrence is performed by using the following key messages and a combination of key messages:

- 'Bioplastic';
- 'Bioplastic' AND 'Sustainability';
- 'Agriculture' AND 'Waste' AND 'Biopolymer'.

A keyword co-occurrence analysis shows the co-occurrence network of keywords and displays it on a two-dimensional map. The VOS viewer provides a clustering function, which shows the keywords in clusters based on their co-occurrence [40].

All references are downloaded and transferred to the VOS viewer software to identify the occurrences between keywords and abstracts. VOS viewer provides bibliometric maps in a more straightforward form and visualizes the co-occurrence network of terms [41]. The period for the bibliometric analysis is considered with no time limitation. However, the studies included in the analysis are published no later than December 2021.

4. RESULTS AND DISCUSSION

4.1. Worldwide bibliometric analysis

Different databases have been used to analyse worldwide research, knowledge, and interest in bioplastics. First, the number of documents published by various countries has been studied using the 'bioplastic' keyword; the first twenty countries with the published papers are shown in Fig. 2. The United States has the highest number of documents (313) among countries, followed by Italy.

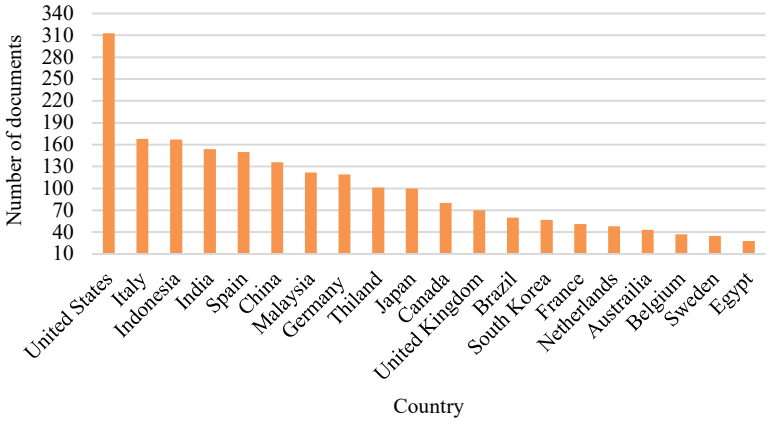

Fig. 2. Documents published per country.

Second, documents published by year have been analysed by choosing the 'bioplastic' keyword. Fig. 3 shows that from 2000, interest has grown in bioplastics, continuously increasing. In 1947, the first technical bioplastic was introduced [42]. Therefore, with the developing trend and interest in bioplastic, by the end of 2021, the highest number of documents were published.

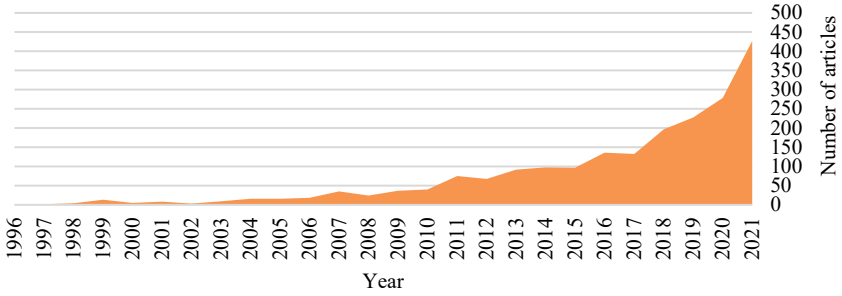

Fig. 3. Documents published per year.

4.2. Keywords co-occurrence analysis

The keyword co-occurrence analysis has been done by analysing the different keywords and combinations. This analysis is done with 2723 scientific documents from the Scopus database. The minimum number of co-occurrences of keywords was set at five.

The global co-occurrences at the abstract and keywords level are shown in Fig. 4. The keywords of each cluster represent its main research area in the domain of bioplastics. The critical research area could be: a) bioplastic properties (green cluster), b) sustainable bioplastic production (blue cluster), c) classification of bioplastics (red cluster), d) biopolymer characteristics (pink cluster), and e) plastic degradation (yellow cluster).

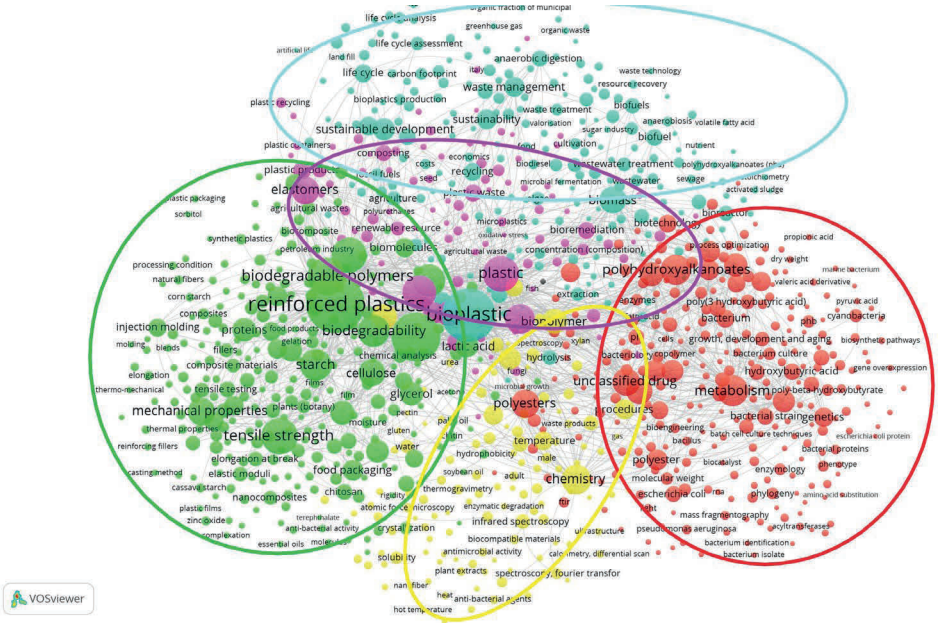

Fig. 4. Visualization of co-occurrences for keyword ‘bioplastic’.

The green cluster co-occurrences with mechanical properties, thermal properties, corn starch, biodegradable polymers, and bioplastic components (starch, glucose, glycerol, cellulose, and pectin). The blue cluster has co-occurrence with the bioplastic, life cycle analysis, sustainability, waste management, sustainable development, bioplastic production, resource recovery, and valorization. The red cluster is the third largest and co-occurrences with the classification of bioplastic, which includes polyalkenoates, polyesters, poly (3hydroxybutyric acid), poly-beta hydroxybutyrate, biocatalyst, and enzymology. The fourth cluster shows the co-occurrences between agricultural waste, bioremediation, microplastic, renewable resources, plastic waste, and extraction. The fifth yellow cluster shows the relation between degradation activities which is enzymatic degradation, antimicrobial activities, anti-bacterial agents, solubility, and biocompatible material.

The bibliometric analysis for keywords ‘bioplastic’ and ‘sustainability’ is shown in Fig. 5. The key research area from the co-occurrences for keywords ‘bioplastic’ and ‘sustainability’ can be framed as: a) sustainable development of bioplastic (green cluster), b) bioeconomy concept (red cluster), c) biodegradable plastics (yellow cluster), and d) assessment methodologies (blue cluster). The green cluster is linked with sustainable development, including bioplastics, biodegradation, packaging materials, renewable sources, and plastic products. The red cluster relates biomass, bioconversion, biopolymer, biorefinery, circular bioeconomy, biotechnology, and sustainability. The yellow cluster shows the link between bioplastic, environmental sustainability, biodegradability, food packaging, and biodegradable plastic. The blue cluster represents the assessment methodologies, including life cycle analysis, economic analysis, and economic and social effects. The purple cluster can be found in different areas and describes terms related to other components.

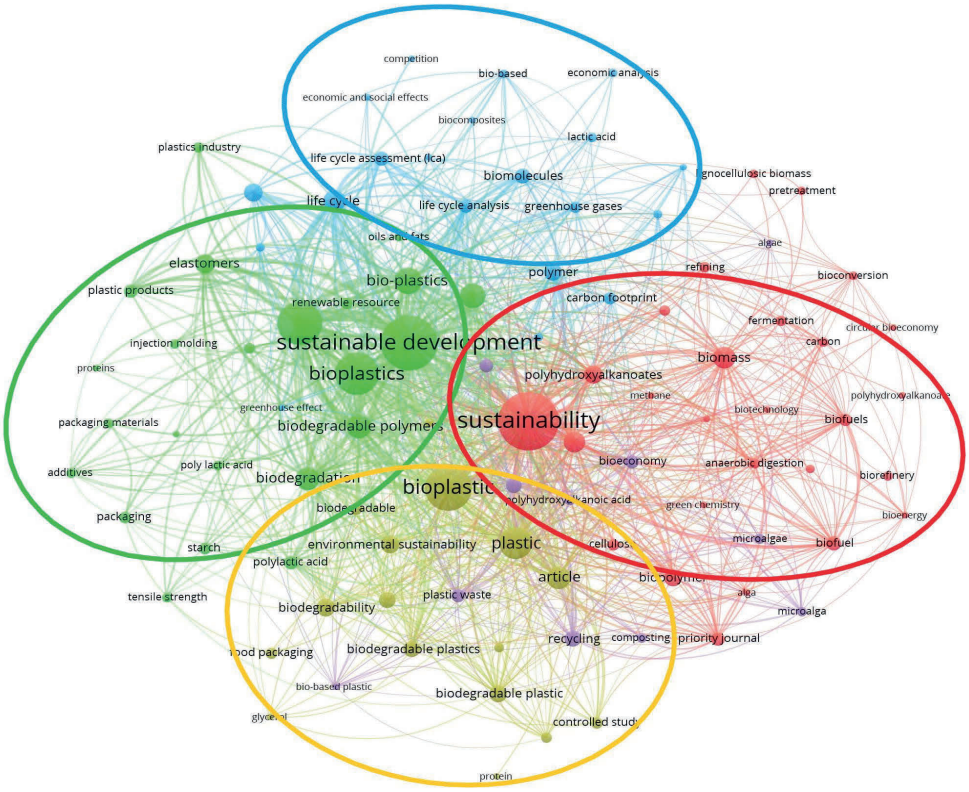

Fig. 5. Visualization of co-occurrences for keywords ‘bioplastic’ and ‘sustainability’.

The bibliometric analysis for the keywords ‘agriculture’ and ‘waste’ and ‘biopolymer’ is shown in Fig. 6. The red cluster shows the main co-occurrence with agricultural waste, valorization, and biopolymers. It also relates to biodegradable polymers, sustainable development, and biomolecules. The blue cluster includes the terms related to biomass activities (biofuel and biogas), such as food industry, waste management, sustainability, hydrolysis, and polysaccharide.

The key research area based on co-occurrences for keywords' agriculture' and 'waste' and ‘biopolymer’ could be framed as: a) agriculture waste management (green cluster), b) biopolymers (red cluster), c) bioproducts (blue cluster), d) industrial waste (purple cluster), and e) biological processes (yellow cluster). The green cluster relates to the agricultural activities with agriculture waste, wastewater, and wastewater management with nanotechnology and biocompatibility. The yellow cluster connects to the biological process, including metabolism, fermentation, extraction, biosynthesis, isolation, and purification. Lastly, the purple cluster shows the link between bioplastic (polyhydroxy alkenoates), waste streams (industrial waste and waste disposal), and tissue engineering biomaterials. This cluster relates to the biomedical application of bioplastics.

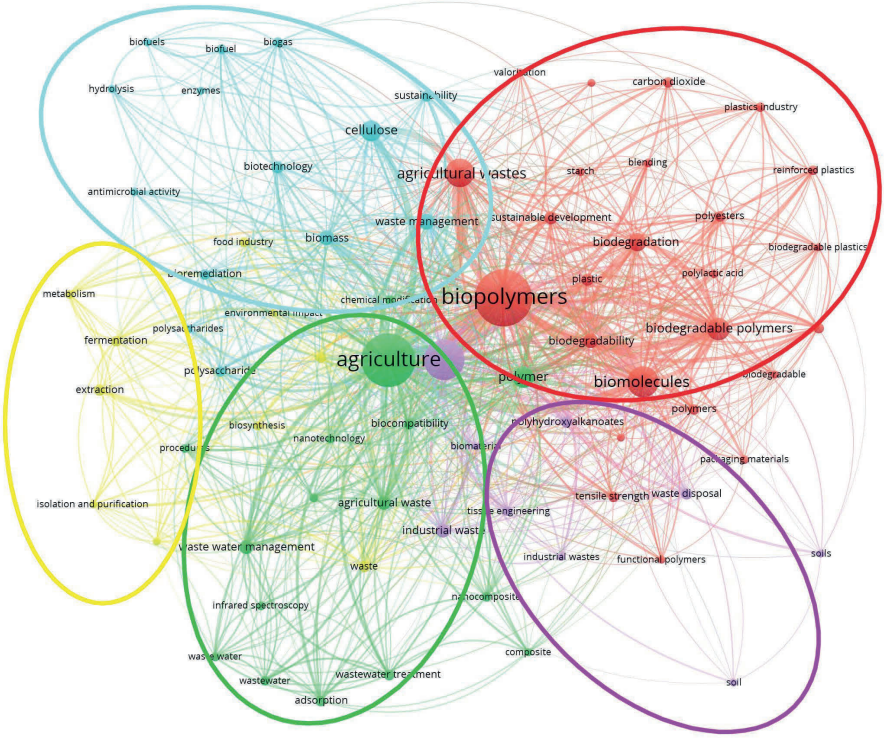

Fig. 6. Visualization of co-occurrences for keywords ‘agriculture’ and ‘waste’ and ‘biopolymer’.

5. Conclusion and Recommendation

This paper presents a review of agricultural waste challenges and approaches. Also, it evaluates the global research trends in agriculture waste, bioplastic production, and sustainable development. Firstly, the findings in the literature suggest that the main reason behind the hurdles in developing sustainability in the agriculture sector is the lack of sustainability strategies and added value approaches. Agriculture waste valorization can be the potential solution for sustainable development of the agriculture sector and give the added value product (bioplastic) that can drive the sector's economic growth.

Secondly, bibliometric analysis has shown a continuously growing research interest in bioplastics since 1998. The main research areas in ‘bioplastic’ are bioplastic properties, sustainable bioplastic production, classification of bioplastics, biopolymer characteristics, and plastic degradation. The main research areas in ‘bioplastic’ and ‘sustainability’ are sustainable development of bioplastic, assessment methodologies, bioeconomy concept, and biodegradable plastics. The main research areas in ‘agriculture’ and ‘waste’ and ‘biopolymer’ are agriculture waste management, bioproducts, biopolymers, industrial waste, and biological processes.

Lastly, the developing research trends are identified along with the research problem. The identified keyword links of each cluster show the scale of existing research, help identify and determine the relationship between subjects, reveal currently existing boundaries of specific

topics, and underline the need for new research directions. The analysis shows main research areas are: a) sustainable bioplastic production, b) agricultural waste management, c) assessment methodology, and d) bioeconomy concept.

The study found that the utilization of agro-waste in bioplastic production is still limited. This is due to the missing link between the bioconversion processes, agricultural waste, and sustainable development goals. While existing research about agro-biopolymer production from agriculture waste focused on environmental aspects, the topic lacks research addressing the economic and social dimensions of sustainability. Therefore, this study recommends more profound content research on agro-biopolymer, bioconversion processes, social and economic aspects.

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