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SYSTEMATIC LITERATURE REVIEW WITH BIBLIOMETRIC ANALYSIS FOR THE ESTABLISHMENT OF A BASELINE FOR ALTERNATIVE MATERIALS

THESIS

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Present:

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SYSTEMATIC LITERATURE REVIEW WITH BIBLIOMETRIC ANALYSIS FOR THE ESTABLISHMENT OF A BASELINE FOR ALTERNATIVE MATERIALS

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RESUMEN GENERAL[1]

REVISIÓN SISTEMÁTICA DE LA LITERATURA CON ANÁLISIS BIBLIOMÉTRICO PARA EL ESTABLECIMIENTO DE UNA LÍNEA BASE PARA MATERIALES ALTERNATIVOS

La contaminación de los suelos agrícolas por el uso excesivo de plásticos sintéticos en la cadena de producción y suministro de alimentos ha provocado la translocación de compuestos cancerígenos y disruptores endocrinos. contenidos en sus formulaciones, a cuerpos de agua y cultivos llegando a la cadena alimentaria, colocando en riesgo la salud humana. En esta investigación se estableció el estado actual del conocimiento del uso de materiales alternativos en la agricultura, adaptando la metodología de revisiones sistemáticas de literatura; este trabajo permitió establecer hipótesis que conducen a una investigación clara, objetiva e imparcial. Se encontró que existe ambigüedad en los conceptos que se refieren a materiales alternativos y se propuso terminología adecuada. Los materiales de mayor interés científico son las películas de plástico, acolchado y la liberación controlada. La investigación aún es un tema emergente en términos de cantidad y colaboración entre países de todo el mundo. Aunque se han propuesto alternativas, pocos materiales garantizan una degradación total y segura en el entorno del suelo. Se obtuvieron fibras de *Agave Salmiana*, se trataron con álcali, se hilaron para obtener hilos y un tejido textil tipo tramado. Estos tres productos se impregnaron con cera de abeja mediante una bolsa de vacío; para compararlos con sus homólogos sintéticos, se midieron los diámetros y la pérdida de peso de los materiales. La mayor pérdida de peso en todos los especímenes se presentó en las fibras, hilo y malla impregnados de cera en un rango de 12-38% en un período de 30 días, contando con diferencias significativas con los productos sintéticos. Estos hilos y malla de fibras naturales se presentan como una propuesta para disminuir el excesivo uso de plásticos sintéticos en la agricultura, sin embargo, es necesario la caracterización mecánica para que se pueda considerar una alternativa funcional.

Palabras clave: materiales alternativos; *Agave Salmiana*; contaminación del suelo; plásticos sintéticos; plástico acolchado

[1] Tesis de Doctorado en Ingeniería, Posgrado en Ingeniería Agrícola y Uso Integral del Agua, Universidad Autónoma Chapingo

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GENERAL ABSTRACT[1]

SYSTEMATIC LITERATURE REVIEW WITH BIBLIOMETRIC ANALYSIS FOR THE ESTABLISHMENT OF A BASELINE FOR ALTERNATIVE MATERIALS

The contamination of agricultural soils due to the excessive use of synthetic plastics in the food production and supply chain has caused the translocation of carcinogenic compounds and endocrine disruptors contained in their formulations to water bodies and farms, getting onto the food chain, generating diseases, and putting human health at risk. This research established the state of knowledge by using the methodology of systematic literature review, enabling the establishment of hypotheses leading to focused, objective, and unbiased conclusions. It was found that there is ambiguity in the scientific literature regarding the terms that refer to alternative materials, so based on the results, appropriate definitions were proposed. The materials of most scientific interest were plastic films, mulching films, and controlled-release materials, which are still emerging topics in terms of quantity and collaboration between countries worldwide. Although some alternatives have been suggested, only a few ensure total and safe degradability on the soil environment. One of the gaps is the lack of methodology on the identification, quantification, and interactions of plastic particles under field conditions with heavy metals, phthalate esters, and organic matter contained in the soil. Agave Salmiana fibers were obtained, treated with alkali, and spun into yarns and a piece of woven textile fabric. These three products were impregnated with beeswax using a vacuum bag; to compare them with their synthetic counterparts, the diameters and weight loss of the materials were measured. The highest weight loss in all specimens occurred in the wax-impregnated fibers, yarn, and nets in the range of 12-38% over a period of 30 days, with significant differences with the synthetic products. These natural fiber yarns and netting are presented as a proposal to reduce the excessive use of synthetic plastics in agriculture; however, mechanical characterization is necessary for them to be considered a functional alternative.

Keywords: alternative materials; Systematic Literature Reviews; *Agave Salmiana* soil contamination; synthetic plastics; mulching film

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1. GENERAL INTRODUCTION

1.1 Background

Synthetic plastic production worldwide is growing at an alarming rate. Reports show that in 1950 approximately 2 Mt. were produced, and in 2019 the production was 368 Mt. (Manufacturers 2020). Future production trends estimate an 8.4 % compound annual growth rate (Geyer, Jambeck, and Law 2017). Degradation time for these materials is a worldwide concern: it ranges from 58 years for bottles to 1,200 years for plastic pipes made from high-density polyethylene (HDPE) (Chamas et al. 2020). Additionally, the degradation process releases chemical substances that pollute aquatic and terrestrial ecosystems (Gewert, Plassmann, and Macleod 2015). The first contamination reports of aquatic ecosystems by plastics appeared in the early '70s; however, the first scientific articles evidencing this type of contamination were published in 2004 (Renner, Schmidt, and Schram 2018). The amount of polluting plastic in water bodies is increasing; Horton et al. estimated that by 2025, it could increase threefold the 50 Mt. reported in 2015. As for soil contamination, little scientific data exists. However, pollution might be 4 to 23 times higher than in aquatic reservoirs (Horton et al. 2017; de Souza Machado et al. 2018).

In agriculture, the use of synthetic origin plastics has progressively increased (Clelj 1959). According to the Association of Plastics Manufacturers Plastics Europe (2020) (Manufacturers 2020) 2.3% of the total volume of plastics produced in 2019 was destined for agricultural use. The most commonly used materials are polyethylene (PE), polypropylene (PP), ethylene-vinyl acetate copolymer (EVA), polyvinyl chloride (PVC), while polycarbonate (PC) and polymethylmethacrylate (PMMA) are used less frequently (Tudor et al. 2019). According to Jansen et al. (2019), flexible plastics for crop protection represent 90% of the total used in this area.

The use of plastics in the agriculture deliver advantages to users in terms of quality, cost, durability, and functionality. However, after their useful life period, there is no recycling strategy, which leads to the generation of unregulated deposits (landfills) or unregulated dispersal on the soil surface. Thus, to solve this problem, new materials have been developed with allegedly a shorter degradation time and lower toxicity during this process while preserving the benefits of their synthetic counterpart.

1.2 Justification

The rapid increase in the generation of scientific articles makes the need for a proper literature review more objective and organized; reading, synthesizing, and answering questions to establish a clear and unpublished research baseline, the model of a systematic review gives an effective method that can successfully lead to less biased evidence-based conclusions. One of the most urgent environmental problems to solve its pollution from anthropogenic activities, such as pollution, from the use of synthetic plastics in agriculture.

Each year amount of 10 million tonnes of plastic enter the ocean, terrestrial soils are considered even the highest sink of microplastics than the ocean, close to 79% of the total plastic waste is in landfills (katsumi). The plastics in their formulation have plasticizers and flame retardants, mostly PAEs (phthalate esters), which can migrate from plastic to soil and then to plants (Serrano ruiz), it has been reported his presence in agricultural fields under plastic mulching and also in the vegetables cultivated in greenhouses conditions (CHEN N. et al. 2017) Human health risk assessments that the consumption of contaminated vegetables presents a high risk for the population (Kong et al. 2012) as oxidative stress, inflammation, translocation, and cancer (Prata et al. 2020).

For this reason, the assessment of an adequate baseline using a systematic literature review is essential for the research in the development of alternative materials where their raw material is from renewable and natural sources to replace synthetic plastics is urgent to reduce the risk to the environment and human health.

1.3 General purpose

Develop and characterize a Agave salmiana fibers for the use as agricultural rope and a shade netting

1.4 Specifics purpose

- Present and analyze advances in the development of research on alternative materials for use in agriculture.

- Identify and analyze research advances in the development of bioplastics to protect grains and seeds.

- Describe and analyze the contamination of agricultural soils by synthetic plastics.

- Develop a shredding blade for desfribrate *Agave Salmiana*.

- Obtain and characterize Agave salmiana fibers for the use as agricultural rope and shade netting.

1.5 Hypothesis

Systematic reviews with a bibliometric analysis allow to identify and evaluate globally with a rigorous and reproducible design the state of the art of any topic or phenomenon of research interest.

Obtaining natural fibers from *Agave Salmiana* allows the development of an alternative material to replace agricultural rope and shade netting for use in agricultura, provide a sustainable, low cost, long-lasting, applicable, and reproducible solution to minimize contamination of agricultural soils and risks to human health.

1.6 Thesis structure

The thesis is made up of a series of seven chapters that follow a chronological order of the research, containing the articles derived from it. The first chapter presents a general introduction, justification, hypothesis, and objectives derived from the research problem. Chapter 2 is a literature review that begins with an overview of natural fibers, then a definition and methodology of the systematic literature review and bibliometric analysis, followed by a look at the different ways of naming the alternative compounds that have been developed, then the introduction of the development of bioplastics for seed and grain protection and finally, the contamination by the presence of plastics in agricultural soils. Then chapter 3 is a systematic literature review with a bibliometric analysis showing an overview of alternative materials used in agricultura, published in January 2022 on the Journal of Agricultural Sciences-Sri Lanka. Chapter 4 presents a systematic literature review with a bibliometric analysis where bioplastics that have been used for grain and seed protection are analyzed globally which is under evaluation in Agrociencias. In chapter 5, a systematic literature review with a bibliometric analysis analyzes the contamination of agricultural soils by the use of plastics which is under evaluation on the Journal of Agricultural Sciences-Sri Lanka. Chapter 6 presents an article where Agave salmiana fibers are extracted, characterized, and used for the development of a shade net for agricultural uses. Chapter 7 is a utility model of an Agave shredding blade, the technical drawing,

2. REVIEW OF LITERATURE

2.1 Natural fibers

One of the most important challenges in the last two decades is the protection of the environment and natural resources, it is necessary the develop and use new strategies or technologies to minimize damage to the ecosystems. Therefore has driven the need to seek new alternatives that could replace the use of synthetic materials due to the high energy and environmental costs involved in the extraction, processing, and disposal an alternative is the development and use of materials with less environmental impact (Lomelí 2018, Ramamoorthy et al. 2015, Taborda et al. 2017).

Natural fibers as reinforcement have been used since ancient times, in the Great Wall of China, whose construction initially began in 121 BC, using clay bricks made from local materials, red willow reeds and branches with gravel during the Han dynasty (209 BC), and then with clay, stone, willow branches, reeds and sand during the Qin dynasty (221-206 BC) (Satyanarayana et al. 2009); in the 20th century, in 1941, Henry Ford used agricultural-based polymer materials composed of paper and soybean resin for automobile parts (Bledzki et al. 2012), however, synthetic fibers supplanted natural fibers due to their competitive price, higher production, and performance (Bledzki et al 2015).

Recently fibers such as hemp, jute, cotton, flax, coconut fiber, kenaf, pineapple leaf fiber, banana leaf fiber (Ticolau et al. 2010), wood fiber, rice husks, wheat, barley, oats, rye, cane (sugar and bamboo), ramie, oil palm, sisal, kapok, raffia (Jawaid et al. 2011) and Agave bagasse (Sierra et al. 2016) have been used as reinforcements in different polymeric matrices. Particularly in Mexico, the Agave generates thousands of tons of waste annually have not been significantly exploited (Caballero et al. 2008, Olivera et al. 2018, Hidalgo et al. 2015).

Natural fibers obtained from plants, animals, and minerals in abundance in the world (Ticolau et al. 2010), are classified according to their origins, from stems, leaves, fruits and, seeds. The chemically composed are cellulose (45-55%), hemicellulose (25-35%), lignin (20-30%) it represents 90% of the dry weight (Ogita et al. 2017), the other 10% are pectin, waxes, and water-soluble substances (Li et al. 2007). Lignin is considered a vital component, acts as cementing material, binding plant fibers together given resistance to gravity forces and wind (Kalia et al. 2009). Furthermore influences the structural and morphological properties, acting as a protection against biological attacks, but, in the same way, is responsible for UV degradation (Suryanto et al. 2017).

A wide range of natural fibers has been using to reinforce polymer matrix (AL-Oqla et al. 2015). Their use has been widespread due to their properties, abundant availability, lightweight, high biodegradability, affordable price, renewable, low abrasiveness to processing equipment, interesting specific properties, as well as good mechanical properties (Kalia et al. 2009). However, they present some limitations, low thermal stability, highly flammable, variation of mechanical properties, high moisture absorption (Mochane et al. 2019), poor interfacial adhesion between the polar-hydrophilic fiber and the non-polar-hydrophobic matrix. In addition, difficulty mixing due to poor wetting of the fiber giving a weak interface (Kalia, et al 2009). Poor adhesion at the interface leads to several drawbacks, environmental attacks that can weaken it, reducing its lifetime (Nurul Fazita et al. 2017). Different strategies have been proposed to minimize the limiting factors of fibers, such as physical treatments, chemical treatments, and the addition of coupling agents.

Treatment to natural fibers

Adding an organic filler to a polymer matrix results in poor mechanical properties compared to the pure polymer, poor interfacial adhesion between the fibers, which act as filler particles (hydrophilic), and macromolecules of the polymer matrix (generally hydrophobic) (La Mantia et al. 2011). Therefore, surface treatment of natural fibers with chemical, physical, physicochemical and biological treatments, as well the use of adhesion promoters, are viable alternatives to improve overall mechanical properties (tensile strength, flexural strength, and modulus), interfacial interactions between filler particles, and polymer matrix (Zhang et al. 2017; Gurunathan et al. 2015).

Some surface treatments reported are Chemical(Alkali treatment, Silane treatment, Stearic acid treatment, Acetylation, TDI (Chloroform and catalyst) treatment, Benzoylation, Anhydride treatment, Permanganate treatment, Peroxide treatment, Sterification, Isocyanate treatment, Polymer grafting), Physical (Mechanical (calendering, stretching), Heat treatment, Steam explosion), Physicochemical (Fiber bleaching, Plasma treatment, Tap water soaking, Ultrasonic with tap water, Laser exposure, γ-rays, and UV radiation) and, Biological treatment (Use of enzymes and fungi). In addition, the use of compatibilizing or coupling agents such as silanes, maleated polypropylene (MAPP), and titanates (Zhang et al. 2017, Jawaid et al. 2011, Li et al. 2007, Cho et al. 2007, Geng et al. 2008, La Mantia et al. 2011, Mochane et al.2019).

2.2 Systematic literature review

The systematic review defines as a summary of the existing literature, finding the focus, trends, and issues of current research (Dora et al. 2020; Meredith

1993). Used for identifying, evaluating, and interpreting all available research with a reproducible design, synthesize the studies published to answer specific questions related to a particular topic area or phenomenon of interest (Budgen and Brereton 2006; Konur 2012; Márcio et al. 2016).

The process consists of gathering information, followed by a rigorous analysis (Márcio et al. 2016). For academics, the reviewing process increases methodological rigor. For practitioners, managers, and stakeholders, a systematic review helps develop a reliable knowledge base by accumulating knowledge from a group of studies (Tranfield et al. 2003).

The first stage conducts a review of all potentially relevant citations identified in the search. After a more detailed evaluation, the full-text read is necessary, and by the criteria, the articles will be part of the systematic review (Borrego et al. 2014).

Methodology of systematic literature review

There are several methodologies for conducting a systematic literature review (Budgen and Brereton 2006;Seuring and Gold 2012;Thomé et al. 2016;Mascarenhas et al. 2018; Baraibar-Diez et al. 2020). The most studied are those around medicine with the PRISMA approach (Urrútia and Bonfill 2010). Tranfield (2003) proposed a methodology consisting of 3 stages and 9 phases:

Stage I – Planning the Review or Defining an overall research aim and preparing the search protocol.

- Phase 0. Identification for the need for a review
- Phase 1. Preparation of a proposal for a review
- Phase 2. Development of a review protocol

Stage II – Conducting the Review or Identifying, selecting, evaluating, and synthesizing the relevant research studies or Identifying gaps and defining research questions.

- Phase 3. Identification of research
- Phase 4. Selection of studies
- Phase 5. Study quality assessment
- Phase 6. Data extraction and monitoring progress
- Phase 7. Data synthesis

Stage III – Reporting and Dissemination of the Overall Research Findings or Descriptive reporting of findings and discussion

- Phase 8. The report and recommendations
- Phase 9. Getting evidence into practice

The main steps are outlined in Figure 2.1 and explained in detail (Figure 2.2-2.7) and can be used as a guide when conducting engineering reviews it has to be mentioned that this is an iterative process, where it will be necessary to go back and forth between steps.

Figure 2.1 Summary of steps for conducting a systematic literature review

Review protocol

As the first step of the review after identifying a knowledge gap in the research field, it is vital to establish detailed, clear, and reproducible guidelines, an a priori protocol, so called because of the nature of research, which is an iterative process.

The objective can be as broad as you wish to investigate the topic should be clear, as it will guide the scope of the research; it should support and be directly related to the research questions as well as the exclusion and inclusion criteria. Is recommended to follow the PRISMA checklist for Scoping Reviews (Tricco et al., 2018). Research questions are closely related to the proposed objectives an adequate ask facilitates the search for information.

This type of review will have the main question then adding sub-questions will contribute to the depth, so the number you have will depend on how much you want to know about the topic; depth should not be confused with breadth. How far you go will depend on your objectives, comprehensiveness will always be the desired quality as it is proportional to how many sources you include in the review (Pham et al., 2014).

Inclusion and exclusion criteria should be established before starting the search for information, as they will contribute to an adequate selection of keywords. They were grouped into two clusters, general ones as years considered, language, publication status, type of publication, geographical location, institutions, etc.; and specific ones that are related to the objective, research questions, methodologies and equipment used, tests performed, taxonomy, technological developments, etc. (Figure 2.2) (Trico et al., 2018) .

Figure 2.2 Review Protocol

Relevant information

As this is a review that seeks to provide a general response, the search sources should be extensive to ensure the quality of the information must include the major number of databases that contain peer-reviewed journals (this will be a parameter of quality in the scientific papers), the most important databases are Scopus, Web of Science, EBSCO, ScienceDirect. Other types of information are conference proceedings, feedback from experts in the field (which is difficult when dealing with emerging topics and therefore little studied), and even the so-called "grey literature" the difficulty of using this type of literature is to assess the quality of the information.

If the sources of information are not diverse, there may be a risk of bias in the results and conclusions, especially when the objective of these reviews is to support or inform decision-making in the creation of public policies or in the establishment of new lines of research in the various areas that can be applied (Figure 2.3) (Pham et al., 2014).

Figure 2.3. Sources of relevant information

Selection of studies

Keywords should be selected to answer the main objective. First, to avoid bias, general concepts are used, and the process must be rigorously and iteratively, repeating steps if necessary, after more specific concepts are used to guide the search to the thematic area; when using databases, at least the Boolean logical operators "AND" and "OR" should be used (Maçaira et al., 2018). When is possible, it is recommended to export the metadata obtained (Title, Abstract, References, etc.) to a citation manager and spreadsheet.

Subsequently, the documents obtained should be analyzed, first making sure that there are no repeated elements, and when they exist, they are discarded. With a minimum of two researchers, the remaining articles should read the titles and abstracts independently to minimize bias it is recommended to order them and first read them in descending order and, then in ascending order, those that do not partially meet the inclusion and exclusion criteria should be eliminated, discrepancies, in the opinion of the collaborators, should be resolved with the intervention of a third party. For the remaining articles, the procedure should be followed, but now each remaining article should be read in its entirety to discard those that were outside the subject of study (Figure 2.4).

Duplicate papers and misspellings should be checked, and the different spellings of a name author, in keywords synonyms o abbreviations (Aria and Cuccurullo, 2017). Finally is recommended to place all the data in an Excel® spreadsheet to create the matrix comprising all the documents used for the meta-analysis or bibliometric analysis.

Figure 2.4 Selection of studies

Meta-analysis/Bibliometric analysis

With the data matrix from the previous step, a bibliometric analysis will be used. The bibliometric analysis aims to find out connections between authors, and countries, identify emerging and influential topics, and point out information gaps (Baraibar-Diez et al., 2020) using meta-analysis tools to obtain graphs and numerical data.

There is various software that helps to carry out this work, the most important is the statistical software "R" the Bibliometrix 3.0 tool: Biblioshiny (Aria and Cuccurullo, 2017), another that has had a boom in recent years VOSviewer version 1.6.14 (www.vosviewer.com; Van Eck and Waltman, 2009) and finally SciMAT (Cobo, 2012), the results will be a report in numerical data, maps, in general, graphical elements. Some examples are strategic diagrams, maps to assess the relationship between researchers, institutions, and keywords (Krauskopf et al., 2018), and evolution maps, which help to give precise answers to the research questions (Figure 2.5).

Figure 2.5.Meta-analysis/Bibliometric Analysis

Results

The presentation of the results should use maps, tables, and diagrams obtained from the previous steps in a descriptive format, and it has a close relation to the title, objectives, and research questions (Figure 2.6). It will be evidence of the need for further development of accurate research topics or as support for decision-making.

Figure 2.6. Presentation of results

Article writing

The writing of the review article must preserve the rigor of a scientific article, use the PRISMA methodology for "Systematic Litearure Reviews" as a guide, follow the steps presented therein, and thus contribute to the assurance of the rigor of the report, therefore, reviewers and readers will have confidence in the data presented and the conclusions derived from the analysis (Figure 2.7) (Verdejo, 2021).

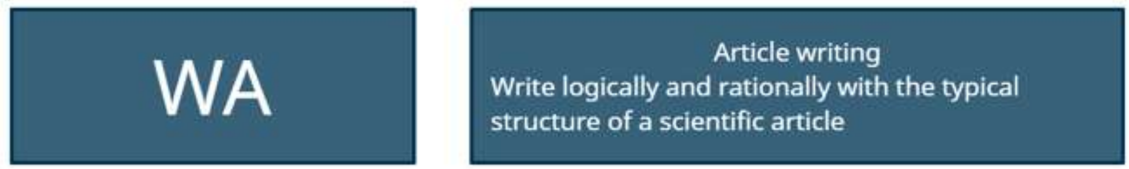

Figure 2.4. Report writing in the form of an article

2.3 Bibliometric analysis

Bibliometric analysis is a quantitative method that includes a mathematical and statistical analysis, measures citation researchers, institutions, research teams, and countries. Analyzing and identification national and international networks to map the development of new (multi-disciplinary) fields of science and technology, works for scholarly journals, books, and researchers (De Montis et al. 2017; Shonhe 2020). Also, utilizing specific indicators to obtain information regarding the output of research activity from written publications, examine the knowledge structure and development in research fields, know whether there are connections among authors, countries, and identifying emergent and influential themes and, point out gaps about the subject (Romero and Portillo-Salido 2019; Baraibar-Diez et al. 2020; Fortuna et al. 2020). The application of bibliometric analysis and data visualization have been widely used tools to measure and evaluate quantitatively and qualitatively scientific research (Sweileh et al. 2018; Sweileh 2021). Provides information for comparative purposes among different countries, authors (Doaa 2016), about research volume and activity of institutions for better allocation of funding.

Software for bibliometric analysis

Several number of software can be used, most used are, R-tool for Bibliometrix 3.0 software: Biblioshiny (Aria and Cuccurullo 2017) and VOSviewer version 1.6.14

The software VOSViewer generates maps to evaluate the relation between terms related to researchers, institutions, and keywords (Krauskopf 2018) on the topic. Bibliometric indicators as bibliographic coupling, co-authorship, and co-occurrences can be obtained, with authors, countries, and all keywords as the unit of analysis. VOSviewer gives equal weight to co-authorship, citation of a publication ("fractional counting") regardless of the number of authors, citations, or references thereof (Perianes-rodriguez et al. 2016).

The VOSviewer software uses a measure of similarity known as association strength, where the index s_{ij} between two terms, *i* and *j*, is calculated with the following equation (Eck and Waltman 2014).

$$s_{ij} = \frac{c_{ij}}{w_i \, w_j}$$

where c*ij* denotes the number of co-occurrences of items *i* and *j*, and w_i and w_j denote either the total number of occurrences of items *i* and *j*, respectively, or the total number of co-occurrences of these items. Therefore, the term *cij* is the number of co-occurrences between articles *i* and *j*. Details of the normalization, mapping, and grouping techniques used by VOSviewer are cited in (Van Eck and Waltman 2009; Waltman et al.2010; Eck and Waltman 2014).

With Biblioshiny can obtain the Annual Scientific Production that measures though years how many articles have been publishing. The author´s scientific production overtime is calculated in terms of the number of publications (Cuccurullo et al. 201) Lotka´s law and H index also can be calculated. Lotka´s law is an approximate inverse-square law where the number of authors publishing a certain number of articles is a fixed ratio to the number of authors publishing a single paper (Elango and Rajendran 2012). H index measures the broad impact of an individual's work and avoids the disadvantages of other criteria it provides an objective measurement of the impact and relevance of an author's academic works (Hirsch 2005).

Biocomposite

Biocomposite materials are materials in which at least one of the constituents originates from natural resources (AL-Oqla et al. 2014) forming by diverse combinations of natural fibers and the polymeric matrix. The term biodegradable biocomposites refer to those compounds in which the polymeric matrix is biodegradable, includes two different families: bio-based and petroleum-based. Biodegradable polymers can be made from biological (biobased) or petroleum bases and are classified as green polymeric matrices (AL-Oqla et al. 2015) (Figure 2.8).

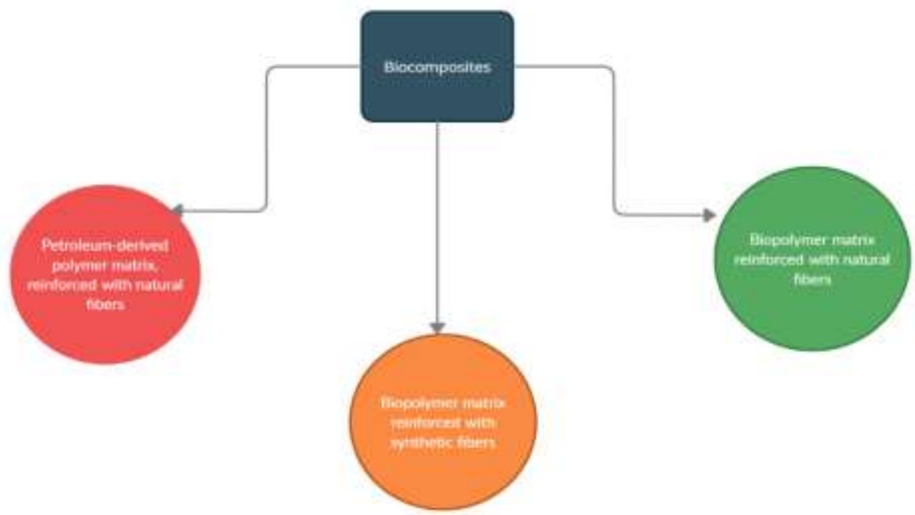

Figure 2.8. Biocomposites classification

Another important classification is "green composites" from natural fibers and biodegradable bio-based polymers, the 100% sustainability and biodegradability of these biocomposites make them very attractive for the replacement of some traditional polymeric composites.

The use of plastic in agriculture gives advantages of quality, cost, durability, and functionality. However, after their life period, there is no recycling strategy, which leads to the generation of unregulated deposits (landfills) or unregulated dispersal on the soil surface. Thus, to solve this problem, new materials have been developed with allegedly a shorter degradation time and lower toxicity during this process while preserving the benefits of their synthetic counterpart.

2.4 Alternative materials to plastics used in agriculture

Existing concepts for naming alternative materials to synthetic plastics in the scientific literature are diverse (Horejs 2020). These concepts are related to the nature of the materials used for manufacture and their behavior in degradation. Table 2.1 summarizes the definition adopted of these concepts based on the scientific information consulted.

Table 2.1 Primary and secondary concepts used in existing scientific literature.

Primary concept	Secondary concept	References
Biocomposite, Green composite, Eco composite. They are composed by two or more components: • Matrix (polymer or resin [biodegradable or non-biodegradable] • Reinforcement (usually fibers).	**Bioplastic.** Should satisfy one or two of the criteria: • Biotechnological origin: partially or totally bio-based, from a renewable source • Biodegradable and / or compostable. **Biobased.** Polymers that are partly or wholly from renewable resources (**biomass**). **Biomass** must be of biological origin, not from geological and/or fossil sources. Biopolymer. They are not by nature biodegradable or compostable. They are polymers extracted from: • Biomass (natural polymers), also well-known as bioplastics • Polymerized from a biological base • Produced by microorganisms • Derived from biodegradable fossil fuels	(Nagalakshmaiah et al. 2019);(Sapuan 2017);(Haraguchi 2014);(Rudin and Phillip 2013);(Abdul Khalil, Bhat, and Ireana Yusra 2012);(Verma and Fortunati 2019);(Narasimhan, Srikanth, and Poltronieri 2016);(Narasimhan, Srikanth, and Poltronieri 2016); (Niaounakis 2013a);(Kyrikou and Briassoulis 2007)

Agro-plastics, Agromaterials. Made up of agroindustrial waste and co-products with high cellulose content. They are also named biobased. Also called "**green thermoplastic biocomposites from agricultural fibers**"		(Dahy 2017);(Vaca-Garcia 2008)
Biomaterials. These products are biocompatible (they do not interfere with or degrade the biological environment where used), and they interact with biological systems. They can be natural, synthetic, and/or composite. The period of use can be temporary or permanent. Help diagnose and/or treat.		(Raghavendra, Varaprasad, and Jayaramudu 2015)
Oxo-degradable polymers. Traditional polymers, its basic material is oil or natural gas, generally basic polyolefins, polyethylene and polypropylene. These products have a pro-degrading agent such as metallic additives.		(Niaounakis 2013a);(Vázquez-Morillas et al. 2016);(Niaounakis 2013b);(Ammala et al. 2011)
Degradable Those significant changes in properties, appearance, and chemical structure under certain environmental conditions, through one or more steps, a polymer may be degradable but not biodegradable.	**Biodegradable.** A material that can be fully and ecologically degraded by microorganisms (bacteria or *fungi*) in carbon dioxide, methane, water, inorganic compounds and biomass for a specific time limit. This is not dependent on their origin, but rather on their composition. All biodegradable materials are degradable, but not otherwise. **Photodegradable.** Degradation implies the absorption of ultraviolet (UV) light that leads to the generation of free radicals, initiating a gradual reaction with atmospheric oxygen in the presence of light. **Hydro-biodegradable.** Plastics that when exposed to an aqueous solution (chemical based) present hydrolysis and experience a rapid	(Rudin and Phillip 2013);(D. Verma and Fortunati 2019);(Niaounakis 2013b);(Kyrikou and Briassoulis 2007b);(Ammala et al. 2011);(Li et al. 2014);(de Carvalho and Abe 2018);(Siracusa et al. 2008);(Scott 2002);(Wróblewska-Krepsztul et al. 2018)

	decomposition, obtaining bio-assimilable products. **Bioerodable.** Biodegradation is limited at the surface level and can be further degraded in the bulk material without the action of microorganisms, through abiotic disintegration or can be degraded by oxidative or photolytic brittleness. **Thermodegradable.** These polymers initially begin to degrade when the product is exposed to high temperatures. The degradation rate is directly dependent on the temperature.	
Compostable. A plastic that biological allows decomposition under composting conditions, by the action of microorganisms that carry out a total mineralization in carbon dioxide, methane, water, inorganic compounds, biomass and leaves not visually distinguishable or toxic residue. Compostable polymers usually show a higher rate of degradation and disintegration, as well as a lower amount of toxic elements at the end of the degradation process.		(D. Verma and Fortunati 2019)**;**(de Carvalho and Abe 2018)**;**(Niaounakis 2013a)

2.5 Biopolymers used to extend life and properties in seeds and grains

According to FAO (2011), about one-third of the food produced was either lost or wasted. That information has highlighted the urgent need to reduce harvest and post-harvest losses. Food waste generation can have several impacts on three of the four pillars of sustainability, namely, economic, social, and environmental sustainability, and is responsible for high levels of greenhouse gas emissions, food insecurity, and economic loss (Dora et al. 2020). The Sustainable Development Agenda 2030, in the specific goal 12.3, include on the topic of food loss and waste, “By 2030, to halve per capita global food waste at the retail and consumer levels, reduce food losses along production and supply chains, including post-harvest losses”(Fabi et al. 2020), note that most losses occur in the primary production stage. The simplest side of the issue is losses in quantity or quality of food in the early stages of the food supply chain, which tend mostly of inadequate technology (Galford et al. 2020). Choices around agricultural inputs, such as seed and animal breed, can reduce Food Loss and Food Waste (FLW) in later stages (HLPE 2014). Producers may select seed varieties that produce goods with a longer shelf life (Girgenti *et al.* 2014) generate marketable products even under unfavorable conditions (e.g. drought-tolerant seeds) or maintain desirable food qualities.

2.6 Contamination of agricultural land for the use of synthetic plastics

The piece of plastic debris fragment into smaller pieces and decompose in long-lasting periods, up to hundreds of years persisting in the environment ((Khalid et al. 2020) (Zhang and Liu 2018)). On the overdependence of non-renewable resources to achieve the required levels in the production of food (Lin et al. 2009) the most used tools are plastics, which can produce the most ubiquitous and long-lasting changes on the earth's surface (Barnes et al. 2009). Of all the anthropogenic changes into the earth, microplastic pollution is probably the most relentless (Khalid et al. 2020). Plastics transported into environments by wind (Beriot et al. 2021a)(Rezaei et al. 2019) and water (Horton et al. 2017)(Wang et al. 2021). Also are classified by particle size, ranging from plastics (>25 mm) (Yu et al. 2021)(de Souza Machado et al. 2018)(Xu et al. 2020), mesoplastics with a size of 5 to 25 mm (Jabeen et al. 2017) (Yu et al. 2021), microplastics <0.5 µm (Silva et al. 2018) (Yu et al. 2021), and nanoplastics <0.1 µm (Revel et al. 2018)(Wang et al. 2020).

Microplastics are cataloged as primary (manufactured by particular applications) and secondary plastics (resulting from fragmentation or degradation from large plastics) (Zhang et al. 2020); (Ambrosini et al. 2019). The major pathways by which microplastics are introduced into agricultural soils are fertilizer application, sludge from water treatment plants, urbanization, irrigation with wastewater (Lü et al. 2018); soil amendments, compost, plastic mulching (Bläsing and Amelung 2018), greenhouse covers (Blöcker et al. 2020) and roads (Kibblewhite 2018).

Plastics are considered contaminants by the potential to enter into the terrestrial environment, affecting the soil quality, health, and functionality (Snow et al. 2019) among the interactions, acting as a vector of substances like heavy metals, phthalic acid esters (PAEs), inorganic and organic chemical material (Harms et al. 2021) (Khalid et al. 2020). Also, plastic formulations contained plasticizers and flame retardants categorized as carcinogenic, teratogenic, and mutagenic (Bai et al. 2020) (Li et al. 2020). Furthermore must be made clear that contamination is the existence of an element where it should not be or at concentrations above the background (Chapman 2007). The pollution is the result of contamination causing adverse effects in the communities, that is to say, the pollutants are contaminants, but not all contaminants are pollutants (Chapman et al. 2003).

Hence the contamination of agricultural soils by plastics is an urgent theme because of the impact on the environment and human health by entering the chain of food (Beriot et al. 2021b) (Wanner 2021) (Zeng et al. 2020).

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3. ALTERNATIVE MATERIALS TO PLASTICS USED IN AGRICULTURE: A SYSTEMATIC REVIEW AND BIBLIOMETRIC ANALYSIS

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Plastics Alternative Materials used in Agriculture: A Systematic Review and Bibliometric Analysis

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ABSTRACT

Purpose: *To identify, analyze, and synthesize the published research about the developments to replace synthetic plastics used in agriculture; to guide researchers and practitioners from various knowledge areas to identify gaps of information, the most prolific authors, and the influential scientific papers that have been published.*

Research Method: *This paper presents a systematic review with a bibliometric analysis; the search was made on the SCOPUS® database up to November 2020. Subsequently, a selection of articles according to the criteria of inclusion and exclusion was carried out and, using bibliometric indicators, VOSviewer v. 1.6.15 and bibliometrix v. 3.0 software, information were obtained to answer the research questions.*

Findings: *Results indicate low scientific production worldwide; only six articles per year as of 2005. Contributions concentrate on a few researchers and developments such as plastic film, mulching, and controlled release materials, and for new materials polyhydroxyalkanoates (PHA), Polylactic acid (PLA), and Chitosan. The most prolific country is China, with only 13 articles. Siwek P. is the researcher with the most outstanding contribution and permanence with four documents. Dharmalingam S.; Hayes D.G. and, Wadsworth L.C. are the most prolific authors in the field in terms of the H index.*

Research Limitations: *The analysis was done only employing the SCOPUS database, moreover the worldwide production of articles is changing every day.*

Originality/value: *This type of review gives an overview of the knowledge and the development of a topic; this evidence can be helpful to establish a groundbreaking for future investigations.*

Keywords: *Bibliometric indicators, mulch, China, controlled release materials, polylactic acid (PLA)*

INTRODUCTION

Synthetic plastic production worldwide is growing at an alarming rate. Reports show that in 1950 approximately 2 M t (Million tonnes) were produced, and in 2018 the production was 359 M t (PlasticsEurope, 2019). Future production trends estimate an 8.4 % compound annual growth rate (Geyer *et al.*, 2017). The degradation time for materials as one-use plastic bags (LDPE), milk, and laundry bottles (HDPE) in landfill/compost/soil conditions depends on various assumptions such as the constant rate of degradation and surface area: volume ratio, reaction order, size and shape, among others. However, it is estimated that 500 years are required for a complete degradation of an HDPE bottle in the land environment (Chamas

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3.1. Introduction

Synthetic plastic production worldwide is growing at an alarming rate. Reports show that in 1950 approximately 2 M t (Million tonnes) were produced, and in 2018 the production was 359 M t (PlasticsEurope, 2019). Future production trends estimate an 8.4 % compound annual growth rate (Geyer *et al*., 2017). The degradation time for materials as one-use plastic bags (LDPE), milk, and laundry bottles (HDPE) in landfill/compost/soil conditions depends on various assumptions such as the constant rate of degradation and surface area: volume ratio, reaction order, size and shape, among others. However, it is estimated that 500 years are required for a complete degradation of an HDPE bottle in the land environment (Chamas *et al*., 2020). Additionally, the degradation process releases chemical substances that pollute aquatic and terrestrial ecosystems (Gewert *et al.,* 2015). The first contamination reports of aquatic ecosystems by plastics appeared in the early '70s; however, the first scientific articles evidencing this type of contamination were published in 2004 (Renneret *et al.,* 2018). The amount of polluting plastic in water bodies is increasing; Horton et al. estimated that by 2025, it could increase in threefold the 50 M t reported in 2015. As for soil contamination, little scientific data exists. However, pollution might be 4 to 23 times higher than in aquatic reservoirs (Horton, 2017; de Souza Machado, 2018).

The–first reports of the use of plastics in agriculture date back to 1959, describing the use of polyethylene bags instead of pots for planting seedlings beet (Clelj, 1959). According to the Association of Plastic Manufacturers in Europe, (2019), of the total production of 359 M t produced in 2018, 1.75 M t were destined for agricultural use (PlasticsEurope, 2019). The most commonly used materials are polyethylene (PE), polypropylene (PP), ethylene-vinyl acetate copolymer (EVA), polyvinyl chloride (PVC), while polycarbonate (PC) and polymethylmethacrylate (PMMA) (Tudor et al., 2019). The most widely used plastic in agriculture is flexible plastic crop film, about 90% of the total (Jansen *et al.,* 2019).

Plastics for agriculture deliver advantages to users in terms of quality, cost, durability, and functionality (Huang *et al*., 2020).. However, after their useful life period, there is no recycling strategy, which leads to the generation of unregulated deposits (landfills) or unregulated dispersal on the soil surface (Geyer *et al.,* 2017). Thus, to solve this problem, new materials have been developed with allegedly a shorter degradation time and lower toxicity during this process while preserving the benefits of their synthetic counterpart (Shen *et al*., 2020). The principal number of developments focus on plastic mulching film, which are film protection made of raw materials like lignin, polylactic acid (PLA), and polyhydroxyalkanoates (PHA) (Chiappero, 2020; El-malek, 2020; Maraveas, 2020a) Also, controlled release hydrogels based in starch/xanthan gum, chitosan, polylactic acid (PLA), and tamarind kernel gum (Simões, 2020; Mujtaba, 2020; Khushbu, 2020). Research, technology, and legislation are, however, incipient. Under this premise, the current systematic review searched for scientific literature related to developing alternative materials to plastics of synthetic origin that are currently used in agriculture to guide researchers and practitioners from various knowledge areas to identify what are the advances, who are the most prolific authors by knowledge area as well as the most influential countries.

3.2. Metodology

Concept review

An initial keyword search found diverse concepts to classify alternative materials as a substitute for synthetic plastics (Horejs, 2020). The concept is based on the material of manufacturing and the rate of degradability. Therefore, before starting the article search process, a summary table of the different scientific literature concepts used to refer to these materials was required.

Systematic review

A systematic review attempts to answer specific questions related to a particular topic. It consists of gathering information, followed by an analysis that shows the updated panorama of the specific topic (Seuring and Gold, 2012). The systematic review consists of the following stages: (1) Planning and formulation of the problem; (2) Bibliographic search; (3) Data collection; (4) Quality assessment; (5) Data analysis and synthesis; (6) Interpretation;

(7) Presentation of the results; and (8) Study update (Thome *et al*., 2016). For the first stage of this research, after identifying a gap in the research field, it is vital to establish detailed, clear, and reproducible guidelines. To fulfill the objective a set of research questions (RQ) were elaborated by the participants of the working group (Table 3.1)

Table 3.1. Research questions according to the objective.

Number	Research Question (RQ)	Rationale
RQ1	¿How has research progressed in terms of scientific publications?	Establish if the subject is a topic of interest
RQ2	¿Who are the researchers most prolific?	Identify the authors who have contributed to the subject and establish interdisciplinary working groups.
RQ3	¿What country has the most outstanding production of scientific articles?	Distinguish the countries with the highest number of articles on this topic and be able to create networks.
RQ4	¿What materials have been used to replace synthetic plastics in agriculture?	Identify the knowledge gaps and future research

In the second stage, the bibliographic search was conducted using the SCOPUS® database. This database is the largest database of peer-review journals with rigorous selection criteria for publishers (SCOPUS, 2020). Keywords searched were directed towards answering the main objective. First, to avoid being bias, general concepts were used to search for articles related to alternative materials for agriculture. Later, more specific concepts were used to guide the search within the agricultural area with the logical

Boolean operators "AND" and “OR” (Maçaira *et al*., 2018).. This procedure created "search operator blocks" made up of a "primary concept" and "secondary concepts" (Table 3.2). All concepts used in this context were not specific to the form, rate, degradation, or composting procedure of the material in question. Another search criterion was "Article Title, Abstract, Keywords" and only considered documents such as "reviews" and "article research," without restriction on the year of publication and language. This initial search yielded a total of 1,404 references (Table 3.2). Identification and removal of 142 duplicate references left only 1,262 working documents (Figure 3.1). The latest search was updated in November 2020.

Table 3.*2* Set of searches with general and specific keywords.

General and specific keywords	Number of scientific articles
	374

(TITLE-ABS-KEY (biomaterials) AND TITLE-ABS-KEY (agriculture OR farmland OR agricultural OR "Agricultural Soil" OR "Agricultural Land"))	
TITLE-ABS-KEY (agromaterials)	20
TITLE-ABS-KEY (agroplastics)	1
(TITLE-ABS-KEY (bioplastics) AND TITLE-ABS-KEY (agriculture OR farmland OR agricultural OR "Agricultural Soil" OR "Agricultural Land"))	135
(TITLE-ABS-KEY ("Biobased Materials" OR "Bio-based Materials") AND TITLE-ABS KEY (agriculture OR farmland OR agricultural OR "Agricultural Soil" OR "Agricultural Land"))	82
(TITLE-ABS-KEY ("Biocomposites") AND TITLE-ABS-KEY (agriculture OR farmland OR agricultural OR "Agricultural Soil" OR "Agricultural Land"))	180
(TITLE-ABS-KEY (biopolymers) AND TITLE-ABS-KEY (agriculture OR farmland OR agricultural OR "Agricultural Soil" OR "Agricultural Land"))	540
(TITLE-ABS-KEY ("Green Composites") AND TITLE-ABS-KEY (agriculture OR farmland OR agricultural OR "Agricultural Soil" OR "Agricultural Land"))	55
(TITLE-ABS-KEY ("Eco Composites") AND TITLE-ABS-KEY (agriculture OR farmland OR agricultural OR "Agricultural Soil" OR "Agricultural Land"))	9
Total of articles	1404

Subsequently, the remaining articles within each search engine block were chosen randomly and numbered consecutively. Two different collaborators independently read the title and abstract of articles in each block. Articles were first read in descending order and then in ascending order to minimize errors. Discrepancies, in the opinion of the readers, were solved with the intervention of a third. Only 116 documents were left for this review after excluding 1,288 references. The inclusion criteria were articles that focused on "development and comparison of alternative materials to synthetic plastics used in agriculture (example: mulching, ropes, hydrogels for fertilizers and water, to mention a few, according to (Scarascia-Mugnozza *et al.,* 2012)". Following the previous procedure, each remaining article was read entirely to discard those outside the study subject. Twenty-seven references were discarded as the full text was not available. In the end, 116 articles remained, 84 belonged to "article research" and 32 to "reviews". Duplicate and misspelled elements need to be checked, different spellings of an author's name, in the keywords the synonyms, abbreviations, or duplicate element (Aria and Cuccurullo, 2017) were placed in an Excel® spreadsheet. Finally, a matrix comprising all the documents for the bibliometric analysis was obtained.

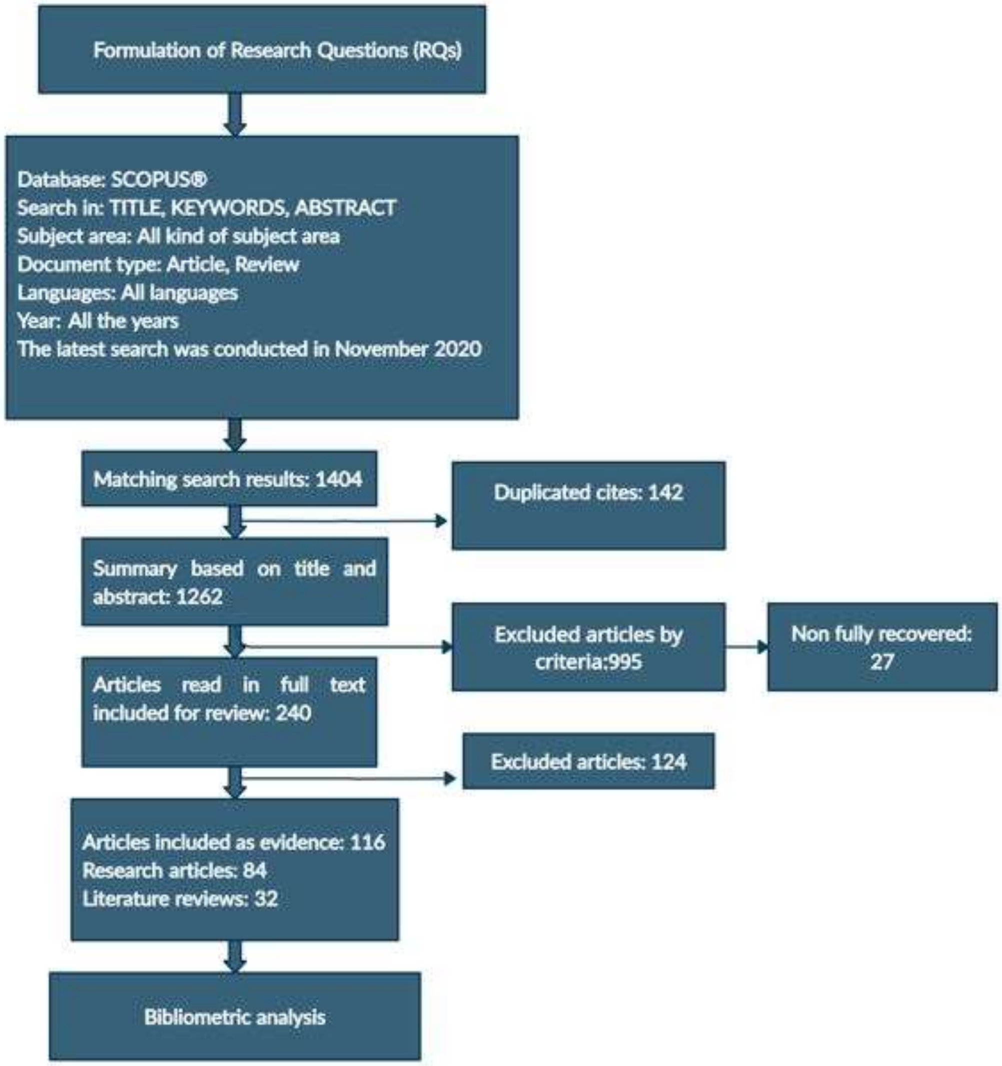

Figure 3.1. Selection procedure of scientific articles. adjusted from Márcio (2016) methodology.

Bibliometric analysis

In a Microsoft EXCEL® spreadsheet, data was collected, and simple frequencies were calculated, this step together with the bibliometric analysis constitutes the third step of the systematic review. The bibliometric analysis aims to know whether there are connections or not, among authors, countries, identify emergent and influential topics, and point outgaps of information (Baraibar-Diez et al. 2020). The bibliometric analysis was conducted with the R-tool for Bibliometrix 3.0 software: Biblioshiny (Aria and Cuccurullo, 2017) and VOSviewer version 1.6.14 (www.vosviewer.com; Van Eck and Waltman, 2009b). Using Biblioshiny, the Annual Scientific Production was obtained, which measures how many articles have been published throughout the years. Also, the author's scientific production obtained over time in terms of the number of publications was calculated (Aria and Cuccurullo, 2017). With VOSviewer, maps were generated to evaluate the relationship between researchers, institutions, and keywords (Krauskopf, 2018) on the topic. The software measures the strength of the relationship between two elements based on the separation distance and through an optimization technique, it forms clusters from a set of tightly related nodes (Van Eck and Waltman, 2009a).

The VOSviewer software uses a measure of similarity known as association strength, where the index s_{ij} between two terms, *i* and *j*, are calculated with the following equation (Van Eck and Waltan, 2014).

$$s_{ij}\,\frac{c_{ij}}{w_i\,w_j}$$

Where c*ij* denotes the number of co-occurrences of items *i* and *j*, and w_i and w_j denote either the total number of occurrences of items *i* and *j*, respectively or the total number of co-occurrences of these items. Therefore, the term *cij* is the number of co-occurrences between articles *i* and *j*. Details of the normalization, mapping, and grouping techniques used by VOSviewer are cited in Van Eck and Waltman, 2009b; The fourth step is the quality indicator. The SCOPUS database ensures the quality of publications; however, this was complemented with the SCImago Journal Rank (SJR) classification criterion by quartiles (www.scimagojr.com/journalrank.php). The quartile is an indicator used to evaluate the relative importance of a specific journal within all the journals in its area. The first quartile, denoted by Q1, contains the highest impact articles; 92% of the articles in this study are within the SJR quartile classification.

Bibliometric indicators of co-authorship and co-occurrences of keywords were obtained, with authors, countries, and all keywords as the unit of analysis. In VOSviewer, equal weight was given to co-authorship and citation of a publication ("fractional counting") regardless of the number of authors, citations, or references thereof (Perianes-Rodriguez et al. 2016), this analysis constitutes the fifth stage. The sixth and seventh steps synthesized the qualitative research coupled to the bibliometric indicators obtained and summarized in the review results. The eighth step is outside the scope of this study.

3.3. Results and Discussion

Concept review

Existing concepts for naming synthetic plastics alternative materials in the scientific literature are diverse (Horejs, 2020). These concepts are linked to the nature of the materials used for manufacturing and their behavior in degradation. Table 3.3 summarizes the definition adopted by each concept based on the scientific information consulted.

Table 3.3. Primary and secondary concepts used in existing scientific literature

Primary concept	**Secondary concept**	**References**
Biocomposite, Green composite, Eco composite. They are composed by two or more components: • Matrix (polymer or resin [biodegradable or non-biodegradable] • Reinforcement (usually fibers).	Bioplastic. Should satisfy one or two of the criteria: • Biotechnological origin: partially or totally bio-based, from a renewable source • Biodegradable and / or compostable.	(Kyrikou and Briassoulis, 2007);(Abdul Khalil *et al*., 2012);(Rudin and Phillip, 2013);(Niaounakis, 2013a);(Haraguchi, 2014); (Narasimhan *et al*., 2016); (Sapuan, 2017);(Verma and Fortunati, 2019)
	Biobased. Polymers that are partly or wholly from renewable resources (biomass). Biomass must be of biological origin, not from geological and/or fossil sources.	
	Biopolymer. They are not by nature biodegradable or compostable. They are polymers extracted from: • Biomass (natural polymers), also well-known as bioplastics • Polymerized from a biological base • Produced by microorganisms • Derived from biodegradable fossil fuels	
Agro-plastics, Agromaterials. Made up of agroindustrial waste and co-products with high cellulose content. They are also named biobased. Also called "green thermoplastic biocomposites from agricultural fibers"		(Vaca-Garcia, 2008); (Dahy, 2017)
Biomaterials. These products are biocompatible (they do not interfere with or degrade the biological environment where used), and they interact with		(Raghavendra *et al.*, 2015)

biological systems. They can be natural, synthetic, and/or composite. The period of use can be temporary or permanent. Help diagnose and/or treat.		
Oxo-degradable polymers. Traditional polymers, its basic material is oil or natural gas, generally basic polyolefins, polyethylene and polypropylene. These products have a pro-degrading agent such as metallic additives.		(Scott, 2002);(Kyrikou and Briassoulis, 2007); (Siracusa *et al*., 2008);(Ammala *et al*., 2011); (Niaounakis, 2013a); (Niaounakis, 2013b); (Rudin and Choi, 2013);(Vázquez-Morillas *et al.,* 2016); (Wróblewska-Krepsztul *et al*., 2018);
Degradable. Those significant changes in properties, appearance, and chemical structure under certain environmental conditions, through one or more steps, a polymer may be degradable but not biodegradable.	Biodegradable. A material that can be fully and ecologically degraded by microorganisms (bacteria or fungi) in carbon dioxide, methane, water, inorganic compounds and biomass for a specific time limit. This is not dependent on their origin, but rather on their composition. All biodegradable materials are degradable, but not otherwise. Photodegradable. Degradation implies the absorption of ultraviolet (UV) light that leads to the generation of free radicals, initiating a gradual reaction with atmospheric oxygen in the presence of light. Hydro-biodegradable. Plastics that when exposed to an aqueous solution (chemical based) present hydrolysis and experience a rapid decomposition, obtaining bio-assimilable products. Bioerodable. Biodegradation is limited at the surface level and can be further degraded in the bulk material without the action of microorganisms, through abiotic disintegration or can be degraded by oxidative or photolytic brittleness. Thermodegradable. These polymers initially begin to degrade when the product is exposed to high temperatures. The degradation rate is directly dependent on the temperature.	(Verma and Fortunati, 2019)
Compostable. A plastic that biological allows decomposition under composting conditions, by the action of microorganisms that carry out a total mineralization in carbon dioxide, methane, water, inorganic compounds, biomass and leaves not visually distinguishable or toxic residue. Compostable polymers usually show a higher rate of degradation and		(Niaounakis, 2013a); (Verma and Fortunati, 2019)

disintegration, as well as a lower amount of toxic elements at the end of the degradation process.

Descriptive bibliometric analysis

The information about the 116 articles published between 1992 and 2021, extracted by the database Scopus® is summarized in Table 3.4

Table 3.4. Main information of bibliometric analyses

Information	Explanation	Number
Documents	Total number of documents	116
Sources	Frequency distribution of sources	73
Author´s keywords (DE)	Total number of keywords	405
Keywords Plus (ID)	Total number of phrases that frequently appear in the title of an article's references	1528
Period	Period of years of the publication	1992 to 2021
Authors	Total number of authors	463
Authors Apppearences	The authors' frequency distribution	531
Authors of single-authored documents	The number of single authors per articles	6
Authors per document	Average number of authors in each document	3.99
Co-Authors per Documents	Average number of co-authors in each document	4.58
Average citation per article	Average number of citations per article	42.47
Collaboration Index	Calculated as the total number of authors of multi-authored articles/total number of multi-authored articles	4.19

Publications

A growing trend in scientific production is observed from 2005 with slight decreases in 2010, 2012, 2015, and 2017 (Figure 3.2). The largest number of publications appears in 2020, with a total of 20 scientific reports. Citations for publications dealing with alternative materials have gradually increased over time, but it might be related to the increment in the number of publications discussed above. On average, each article has been cited 42.47 times and written by four authors (3.99). Additionally, the collaboration index (CI), which is calculated as the total number of authors of multi-authored articles/total number of multi-authored articles is 4.19 (Elango and Rajendran, 2012).

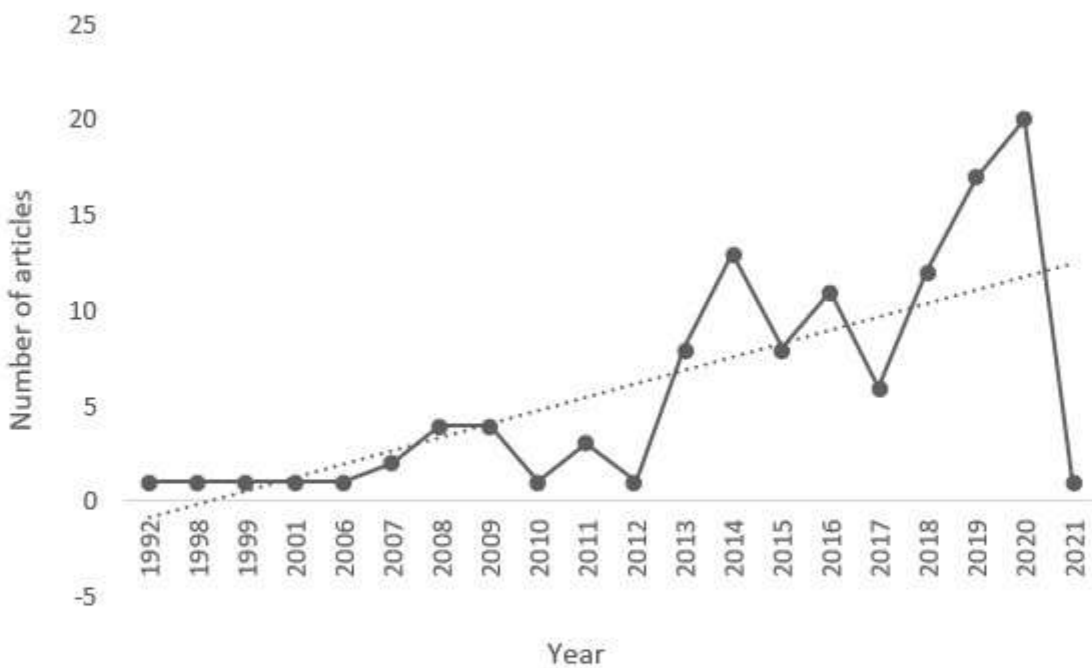

Figure 3.2. Timeline of related scientific publications in alternative materials used in agriculture.

The number of contributions shows that the search for plastic alternatives in agriculture is limited, and deficient in quantity compared to the magnitude of the environmental pollution problem (Scarascia-Mugnozza *et al.,* 2012).

Authors

To find out about the most prolific authors, the author production was measured by the H index and their production over time. H index indicates an estimate of the importance, significance, and broad impact of a scientist cumulative (Hirsch, 2005). For the H index measurement, the 20 main authors were included. In Table 3.5, the ranking of authors by H index, number of citations, number of papers, publication year start, and institution are presented. Dharmalingam S.; Hayes D.G.; Wadsworth L.C. are the most impactful authors in the field with four publications, an H index of 4, 95 times cited, and first published in 2012. The principal subject of these articles is fully bio-based and potentially soil biodegradable agricultural mulches (Hayes, 2012; Wadsworth, 2013; Hablot, 2014; Dharmalingam, 2015). The authors with the highest number of citations are Chandra R. and Rustgi R., with 1052 citations from one publication in 1998. They published a review paper about biodegradable polymers mechanism of synthesis, their degradation mechanisms and, they suggested using these polymers to solve problems for plastics pollution (Chandra and Rustgi, 1998).

Table 3.5. Most prolific author´s according to the H index

Author	H index	TC*	NP**	PYS***	Afilation
Dharmalingam S.	4	95	4	2012	University of Tennessee
Hayes D.G.	4	95	4	2012	University of Tennessee
Wadsworth L.C.	4	95	4	2012	University of Tennessee
Sartore L.	3	67	4	2013	University of Brescia
Schettini E.	3	90	4	2013	University of Bari

Siwek P.	3	18	4	2010	Agricultural University in Kraków
Vox G.	3	90	4	2013	University of Bar
Lee J.	3	42	3	2013	Advanced Manufacturing Research Centre
Yang Y.	3	117	3	2013	Shandong Agricultural University
Chandra R.	1	1052	1	1998	Delhi College of Engineering
Rustgi R.	1	1052	1	1998	Delhi College of Engineering
Tighzert L.	1	587	1	2009	Ecole Superieure d'Ingenieurs en Emballage et Conditionnement (ESIEC)
Vroman I.	1	587	1	2009	Ecole Superieure d'Ingenieurs en Emballage et Conditionnement (ESIEC)
Keshavarz T.	1	517	1	2007	University of Westminster
Philip S.	1	517	1	2007	University of Westminster
Roy I.	1	517	1	2007	University of Westminster

*TC (Total of citations); **NP (Number of publications); ***PYS (Publication year start)

Over time, Siwek P. is the researcher with the most outstanding contribution and permanence in the same research area, followed by Schettini E.; Vox G.; Sartore L. with four and three publications, respectively (Figure 3.3). The evidence shows that the search for alternatives to substitute plastics in agriculture has not received enough attention from the scientific community. The very weak association strength reveals that collaboration mechanisms between researchers and institutions have not been established.

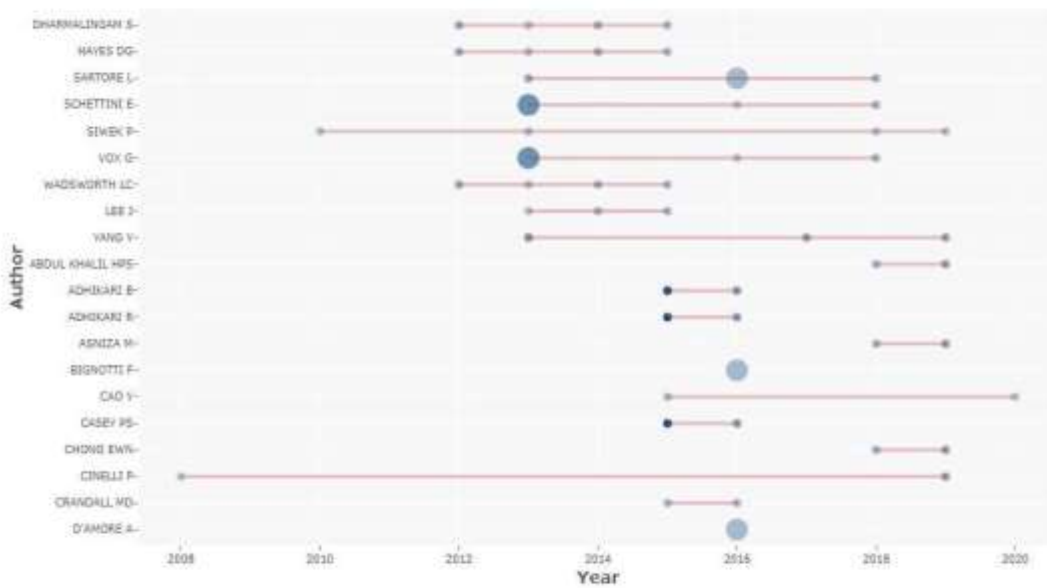

Figure 3.3. Top authors' production over time in the developing of alternative materials (R-tool for Bibliometrix: Biblioshiny, 2020).

Countries

The co-authorship indicators show interactions and the role among countries. In this study, a minimum scientific production of one article per country is considered, the result was a network with 42 countries organized into nine principal clusters based on the total association strength (Table 3.6). China formed the cluster with the highest association strength with 13 publications; the second association strength cluster from United States (fifteen publications). However, India with numerous citations (1319) and articles (13) achieves a low association strength, probably due to affinity in publications with countries that scientifically contribute little to the subject (Van Eck and Waltman, 2009a). Another relevant case is France, which has a higher number of citations from three publications than the country with the largest number of publications. French publications include a literature review cited 587 times (Vroman and Tighzert, 2009) and an application publication comparing four biodegradable materials of mulching, cited 57 times (Touchaleaume et al., 2016).

Table 3.6. Most prolific countries order by cluster.

Cluster	Country	Number of documents	Number of citations	Total link strength
1	Spain	10	201	4
1	Chile	2	11	2
1	France	3	644	1
2	China	13	242	7
2	Turkey	2	45	2
3	India	13	1319	5
3	Canada	3	466	1
4	Malaysia	6	79	5
4	Nigeria	4	47	4
5	Taiwan	5	320	2
5	United kingdom	3	576	2
6	Brazil	8	60	3
7	United States	15	413	6
10	Australia	3	220	0
16	Italy	15	449	0

Emergent themes

The Keywords provide a reasonable description of research hotspots (the attention of scientists focused on research problems and concepts) (Romero and Portillo-Salido, 2019) and are highly effective in bibliometric analysis when investigating the knowledge structure of scientific fields (Zhang et al. 2015). In the present study, the VOSviewer was used to create a bibliometric network of co-occurrence, which contained as an analysis unit all keywords with an occurrence frequency of at least three times, yielded 1,643 words distributed into 4 clusters (Table 3.7). The keywords with the highest occurrence and total association strength related to the objective of this study are mulch, hydrogel and film, with the highest occurrence in the years 2015 and 2017 respectively, and Polyhydroxyalkanoates (PHA), Polylactic acid (PLA), Chitosan, among others, as a raw materials. The larger the number of items in a point, the closer the color is to yellow (Figure 3.4).

Table 3.*7* Most relevant keywords order by year of publication

Keyword	Occurrences	Total link strength	Average publication year
Plastic	13	13	2014
Polyhydroxyalkanoates (PHA)	6	6	2014
Biodegradation	35	35	2015
Biodegradability	32	32	2015
Polymer	29	29	2015
Mulch	14	14	2015
Chitosan	10	10	2015
Biopolymer	51	51	2016
Agriculture	46	46	2016
Biodegradable polymers	27	27	2016
Polylactic acid (PLA)	14	14	2016
Water absorption	12	12	2016
Soil	23	23	2017
Scanning electron microscopy	15	15	2017
Fertilizer	14	14	2017
Hydrogel	13	13	2017

Film	11	11	2017
Slow release fertilizers	7	7	2017

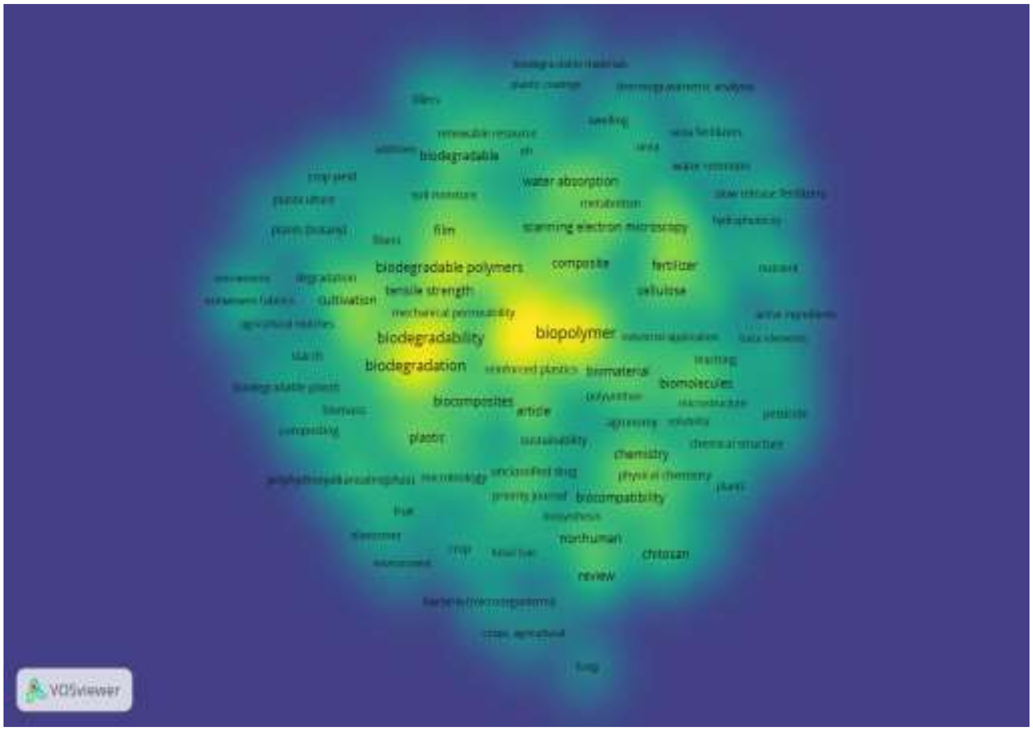

Figure 3.4. Bibliometric network of keywords in development of alternative materials used in agriculture (VOS Viewer, 2020).

This analysis is consistent with the information in Table 3.8, as it shows that developments mostly focus on mulching materials, hydrogels, slow realese fertilizers, and controlled release materials. The analytical techniques most used in the research publications studied were scanning electron microscopy and Fourier-transform infrared spectroscopy. Research might be driven by the recent interest in horticultural production under open skies and greenhouses (Briassoulis et al., 2013). Further research by interdisciplinary groups is needed to develop alternative materials to replace existing ones and determine the rates and forms of degradability (Rujnić-Sokele and Pilipović, 2017). The development of alternative materials from renewable sources has been slow compared to synthetic plastics used; this trend leads to unregulated deposition and the release of pollutants into ecosystems (Geyer et al. 2017). A limitation of this study is that only a Scopus database was used however, the use of this database ensures that the quality of the articles found is high..

Table 3.2. Materials made from renewable sources that are presented as an alternative to replace plastics used in agriculture.

Developments	References
Controlled release, hydrogels, foams, pellets (Water and Fertilizers)	(Li et al., 1992); (Chandra and Rustgi, 1998);(Shih and Shen, 2006);(Velásquez, 2008);(Gómez-Martínez et al., 2009); (Vroman and Tighzert, 2009);(Wang and Wang, 2009);(Fernández et al., 2011);(Singh A. et al., 2011); (Riggi et al., 2012);(Wyatt and Yadav, 2013);(Gómez-Martínez et al., 2013);(Yang et al., 2013);(Cota-Arriola et al., 2013);(Zainescu et al., 2014);(Sharma et al., 2014);(Kaur and Dhillon, 2014);(Chowdhury, 2014);(Pandey and Kumar, 2014);(Ivanov et al., 2014);(Stoykov et al., 2015); (Mukerabigwi et al., 2015);(Timilsena et al., 2015);(Oliveira M. et al., 2015); (Marcelino et al., 2016);(Idumah and Hassan, 2016);(Mohammadi-Khoo et al., 2016);(Alves et al., 2016);(Vinceković et al., 2017);(Liu et al., 2017);(Sharma et al., 2017);(De Corato et al., 2018);(Saratale et al., 2017);(Nangia et al., 2018);(Abdul Khalil et al., 2018a);(Abdul Khalil et al., 2018b);(Sharif et al., 2018);(Saallah and Lenggoro, 2018);(Jiménez-Rosado et al., 2018);(Khushbu et al., 2019);(Skrzypczak and Witek-krowiak, 2019);(Calcagnile et al., 2019);(Xie et al., 2019);(Dabbaghi and Rahmani, 2019);(Wang et al., 2020);(Versino et al., 2020);(Khushbu and Warkar, 2020);(Michalik and Wandzik, 2020);(Feng et al., 2020);(Yin et al.,

	2020);(Verma et al., 2020);(Mujtaba et al., 2020);(Mate and Mishra, 2020);(Klein and Poverenov, 2020);(Martins et al., 2020)
Mulch, Film protection	(Chandra and Rustgi, 1998);(Yang and Wu, 1999);(Bastioli, 2001);(Chiellini et al., 2007);(Philip S., Keshavarz T., 2007);(Kijchavengkul et al., 2008);(Morreale et al., 2008);(Tachibana et al., 2009);(Vroman and Tighzert, 2009);(Siwek et al., 2010);(Dharmalingam et al., 2015);(Hayes et al., 2012);(Riggi et al., 2012); (Wadsworth et al., 2013);(Sartore et al., 2013);(Martin-Closas et al., 2014);(Mühl and Beyer, 2014);(Hablot et al., 2014);(Betas et al., 2014);(Li et al., 2014);(Pang et al., 2014);(Wortman et al., 2015); (Dharmalingam et al., 2015);(Sartore et al., 2015);(Tan et al., 2015);(Briones et al., 2015);(Dinh-Audouin, 2016);(Sforzini et al., 2016); (Touchaleaume et al., 2016);(Wortman et al., 2016);(Adhikari et al., 2016);(Saba et al., 2017);(Rujnić-Sokele and Pilipović, 2017);(Sartore et al., 2018); (Rocha et al., 2018);(Abdul Khalil et al., 2018a);(Abdul Khalil et al., 2018b);(Bucki et al., 2018);(De Corato et al., 2018);(Briassoulis and Giannoulis, 2018);(Oliveira et al., 2019);(Puchalski et al., 2019);(Kołodziejczyk et al., 2019);(Radovanović et al., 2019);(Kuo and Wu, 2019);(Santos et al., 2020);(George et al., 2020);(Mastalygina et al., 2020);(Chiappero et al., 2020);(El-malek et al., 2020);(Maraveas, 2020a)
Pots and bags for cultivation	(Bastioli, 2001);(Riggi et al., 2012);(Schettini et al., 2013);(Lu et al., 2014);(Mühl and Beyer, 2014); (Oliveira T.G. et al., 2015);(Sartore et al., 2016);(Cinelli et al., 2019); (Díez-Pascual, 2019);(El-malek et al., 2020);(Santos et al., 2020);(Adeleye et al., 2020)
Others (Geotextiles, Life cycle analysis, Agrochemical containers for cars, phytoinjectors, seedling nurseries)	(Girgenti et al., 2014); (Kong et al., 2014); (Hsieh et al., 2017);(Lakitan et al., 2019);(Cao et al., 2020)
Nets	(Mukherjee et al., 2019);(Maraveas, 2020a);(Maraveas, 2020b);(El-malek et al., 2020)
Clips, Brackets, Strings	(Mejía et al., 2007);(Vroman and Tighzert, 2009); (Pudełko et al., 2021)

3.4. Conclusion

This systematic literature review with bibliometric indicators updates the progress in contributions and cooperation between researchers and countries developing alternative materials to replace plastics used in agriculture. Results show that their contribution is still emerging in quantity and collaboration among the different scientific actors worldwide. Over the years, it is clear that the research focuses on plastic film, mulching, and controlled release materials. However, many synthetic plastics need to be replaced by materials that guarantee a safe degradability in the soil environment. To achieve this, the obtention and synthesis of raw materials to their final disposal that are safe and friendly to all ecosystems would have a significant impact on solving the contamination of agricultural soils. Finally, there is ambiguity in the scientific literature concepts that refer to alternative materials, so it is convenient to homogenize the terminology to avoid confusion.

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3.7. Conflict of Interest

The authors declare no conflict of interest.

4. SCOPING REVIEW REGARDING RENEWABLE ALTERNATIVE MATERIALS TO IMPROVE QUALITY IN SEEDS

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4.1. Abstract

The purpose of this review was to analyse and synthesise the published research around renewable alternative materials for improving the quality of seeds in order of reducing pollution and raw material depletion. The analysis focused on the productivity per country and authors, and the most relevant keywords. The articles were selected in the SCOPUS® and Web of Science ™ databases with updates until November 20201. Subsequently, they were analysed by bibliometric indicators using VOS viewer v. 1.6.15 and BIBLIOMETRIX v. 3.0 software. Results indicate low scientific production

worldwide, with a total of 61 publications, the largest number of publications appears in 2020, with thirteen scientific reports. The most cited and prolific authors were Abbas, H.K., Accinelli, C., and Shier, W.T. The United States of America was the country with the largest number of publications (14). The most recently used keywords were "chitosan", "biopolymer", "seed coating", "maize (*Zea mays L.)",* "seed treatment", "sustainable agriculture". The most widely documented developments are biostimulants, biocontrol, containers, and protect drought agent. The interdisciplinary collaboration could promote discovering new materials derived from renewable sources that significantly influence the quality of seeds.

Keywords: treatment, protection, coating, dressing, priming

4.2. Introduction

To withstand adverse conditions, such as fungi and insects attack, seeds are usually protected with insecticides, fungicides, coating films, and other polymers that also contribute to modifying their physical characteristics, e.g., permeability, size, and shape. Because of the depletion of raw materials and pollution generated by some agrochemicals and materials, renewable alternative materials have been proposed by several authors and companies to improve the quality of seeds. Materials such as chitin and chitosan have been proposed to improve germination and growth (Amine *et al.*, 2020), vermicompost and soy flour to stimulate growth and development

(Amirkhani *et al.*, 2019) bioplastics for seed coating to reduce dusting (Accinelli, C. et al. 2016; Accinelli. C. et al. 2018b), *Aspergillus flavus* as biocontrol of aflatoxin production (Accinelli, C. et al. 2018a), chitosan and copper nanoparticles to boost defence responses (Choudhary et al. 2017; Divya, K. et al. 2020); bacteria-based biocomposites in order of stabilizing surrounding rhizosphere (Hussain et al. 2019); other materials have been proposed to enhance plant and plantlets development, for example, recycled wastes of tomato and hemp fibers for biodegradable pots (Schettini, E. et al. 2013). The overall extent of the advance of studies on the use and development of renewable alternative materials for seed protection and germination promotion, is unknown; using a scoping review can update the extent of the specific topic and consists of gathering information, followed by an analysis (Verdejo et al. 2021). This type of review increases the methodological rigor and helps the develop well-founded knowledge by accumulating data (Tranfield et al. 2003). A scoping review is a summary of the existing literature, trends, and issues of current research (Pham 2014; Cooper 2021) through a reproducible design for identifying, evaluating, and interpreting the data by the PRISMA statement (Tricco et al. 2018).

The bibliometric analysis is a utility tool to measure and evaluate quantitatively and qualitatively the scientific research (Sweileh et al. 2018 Sweileh et al. 2021) and to compare the connection among countries, authors (Doaa, 2016), research volume, and the activity of institutions for better allocation of funding.

The VOSviewer software is used, in bibliometric analysis, to estimate the association strength between two elements based on the separation distance, for which, it uses an optimisation technique to form clusters from a set of tightly related nodes. The association strength (s_{ij}) between two terms, *i* and *j*, is calculated with the following (Van Eck and Waltman, 2009; Van Eck and Waltman, 2014):

$$s_{ij} = \frac{c_{ij}}{w_i w_j} \qquad (1)$$

where *cij* denotes the number of co-occurrences of items *i, j*, w_i and w_j denote either the total number of occurrences of items *i* and *j*, respectively or the total number of co-occurrences of these items. Therefore, the term *cij* is the number of co-occurrences between articles *i* and *j*. Details of the mapping, normalisation, and grouping methods used by VOSviewer are cited in (Van Eck and Waltman, 2007; Waltman et al. 2010; Van Eck and Waltman, 2014).

The current study aims to show the trend of scientific papers on the new developments of alternative materials for improving the quality of seeds. The study focuses on describing the principal characteristics of the relevant documents, the connection between countries, authors, and emergent themes.

To fulfil the objective, we established a set of research questions (RQ):

RQ1 – How has research progressed in the area of study in terms of scientific publications and citations?

RQ2 – What materials have been developed from renewable sources related to improving seeds?

RQ3 – Who are the researchers with the highest number of scientific reports? What was their citation impact?

RQ4 – What country has the most outstanding production of scientific articles related to the subject of study?

4.3. Metodology

Scoping review

We followed the next five phases (Arksey and O'Malley, 2005):

Phase 1: Defining research question or questions

Phase 2: Identifying all the relevant studies

Phase 3: Selection of the relevant studies

Phase 4: Shaping the data

Phase 5: Gathering, summarizing, and reporting the results

Two considerations known as inclusion criteria were made as follows:

1.– Only documents such as “research article” were considered without restriction on the year of publication or language.

2. – Only papers focused on the development of alternative materials for improving germination, growth, crop yield, and physical, phytosanitary protection of seeds and seedlings were included.

The bibliographic search stage was made using the SCOPUS® and Web of Science ™ databases, these databases are the most complete digital source of scientific articles with peer-review journals with rigorous selection criteria for publishers and the most used in the bibliometric analysis (Sweileh et al. 2018). First, general concepts were used for search articles related to alternative materials for seeds; later, more specific concepts were used to guide the search within the agricultural area with the logical Boolean operators “AND” & “OR” (Maçaira et al. 2018).

Bibliometric analysis

The analysis was conducted with the R-tool for BIBLIOMETRIX 3.0 software: BIBLIOSHINY (Aria and Cuccurullo, 2017) and VOSviewer version 1.6.14 (Van Eck and Waltman, 2009). Annual and authors’ scientific production over time, in terms of the number of publications, was obtained using BIBLIOSHINY; then, Lotka’s law and the H index were calculated. Bibliometric indicators of co-authorship and co-occurrence with countries and all keywords as the unit of analysis. In VOSviewer, equal weight was given to co-authorship and citation of a publication ("fractional counting") regardless of the number of authors, citations, or references thereof (Perianes-Rodriguez et al. 2016)

4.4. Results

The initial keyword search yielded 4,558 references (Figure 4.1), in the end, 61 articles remained in the matrix, comprising all the documents for the bibliometric analysis.

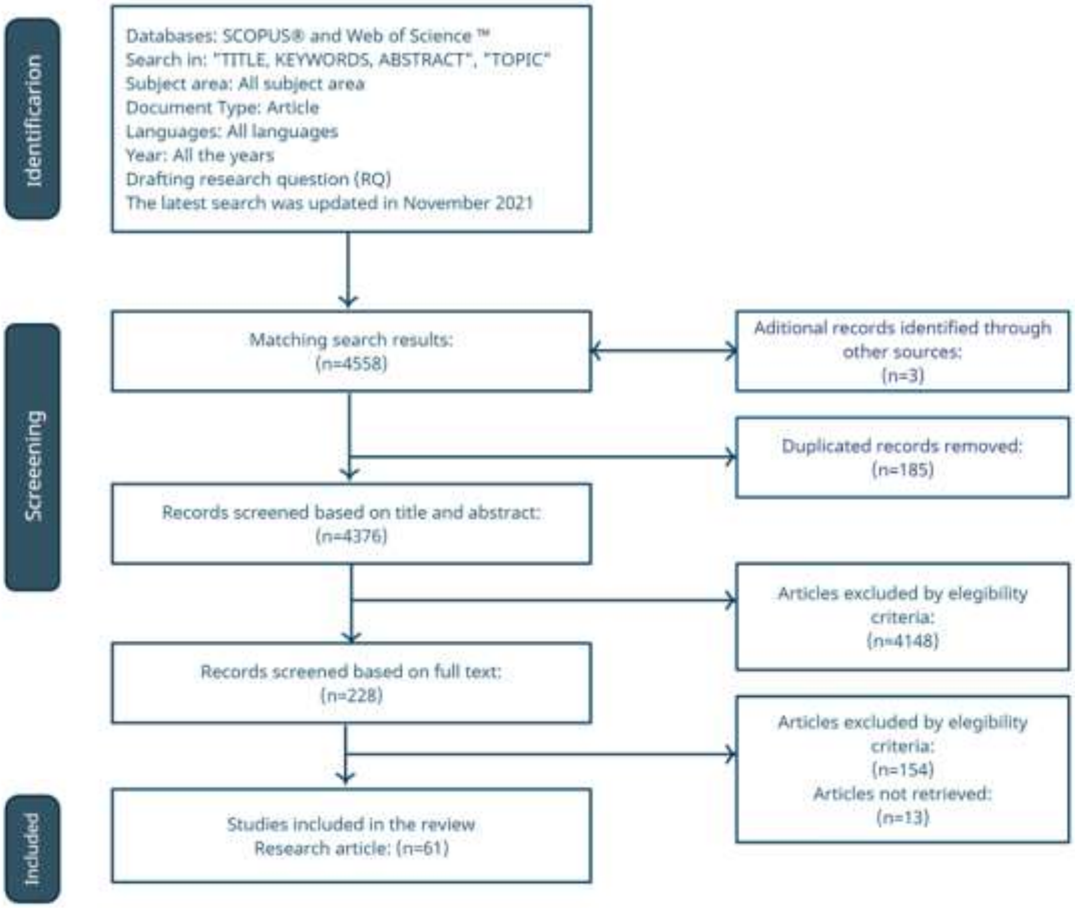

Figure 4.1. Stages of scoping literature review (Author's elaboration, modified from Tricco *et al*., 2018)

Descriptive bibliometric analysis

Table 4.1 summarises the 61 articles published between 2007 and 2021. The most influential journals were *Crop Protection, Journal of Cop Improvement, PLOS One, and Scientific Reports* with two documents, followed by *Sustainable Chemistry and Engineering, Acta Agrobotanica, Acta Horticulturae, African Journal of Biotechnology*, etc. (with one document each). On average, each article has been cited 15 (14.66) times and written by five authors (4.92). The collaboration index (CI) was 5.12.

Scientific production

Citations for publications about materials for the protection of seeds and seedlings have slowly increased over time (Figure 4.2); that increase might be related to the recent concerns about preserving the environment and reducing food loss and waste.

Table 4.1. Main information of articles about renewable alternative materials for protection of seeds

Description of result	**Results**
Period of years of publication	2007:2021
Ocurrence of journals	57
Number of documents	61
Years between each publication (average)	4.59
Number of citations of each article (average)	14.66
Number of citations of each document per year (average)	2.595
Number of the total of references	2,607
Research articles	60
Erratum	1
Total number of phrases that frequently appear in the title of an article´s references	754
Number of keywords	232
Number of authors	300
Articles with a single author	3
Articles with multi-authored articles	297

Number of documents by an author (average)	0.203
Number of authors by document (average)	4.92
Number of co-authors for each article	5.38
Collaboration Index	5.12

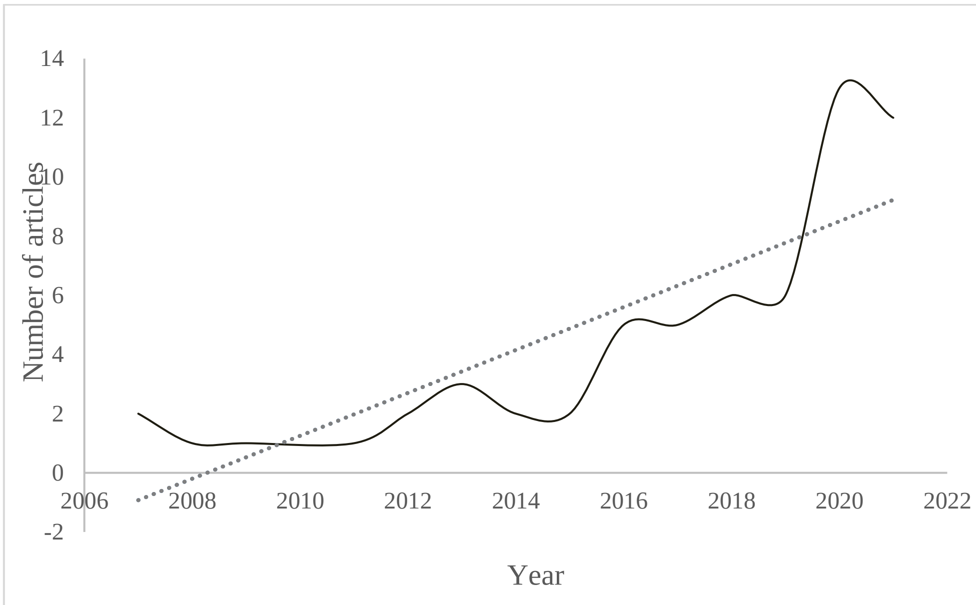

Figure 4.2. Papers published between 2007-2021 about renewable alternative materials for the protection of seeds.

Renewable alternative materials and their applications

Bibliometric network co-occurrence resulted in a total of 183 words distributed into 14 clusters (Table 4.2). The keywords with the highest occurrence and total association strength were chitosan, biopolymer, seed coating, maize (*Zea mays L.),* seed treatment, sustainable agriculture, growth, and rice (*Oryza sativa L*.) (Figure 4.3). As presented in figure 4.4, the most recently used keywords were those related to biomaterial in agriculture, food security, plant biostimulants, seed biopriming and care, e.g., leaf production, shoot elongation, stomatal conductance of leave, nickel toxicity and oxidative stress.

Table 4.2. Network of co-occurrence for unit keywords about renewable alternative materials for the protection of seeds

Cluster	Keyword	Ocurrence	Total link strength	Average publication year
13	chitosan	8	8	2018.38
	antioxidant	2	2	2020
5	biopolymer	5	5	2018
	bioagent	2	2	2020
	seed biopriming	1	1	2021
7	seed coating	5	5	2017.6
	suistainable agriculture	3	3	2020
	biomaterial in agriculture	1	1	2021
	food security	1	1	2021
1	maize (zea mays l.)	4	4	2018
	seed treatment	3	3	2017.67
6	growth	3	3	2016.33
	rice (oryza sativa l.)	3	3	2013
8	plant growth promoting bacteria (pgpr)	3	3	2015.33
	nitrogen-fixing bacteria (microorganisms)	2	2	2019
	stomatal conductance of leave	1	1	2021
12	carum copticum	2	2	2016.5
	salt stress	2	2	2020.5
3	biological control	2	2	2009.5
	rhizoctonia solani	2	2	2015.5
10	plant growth regulator	2	2	2019.5
	salinity	2	2	2015.5
2	biochar	2	2	2018
	heavy metal	2	2	2018.5
	nickel toxicity	1	1	2021
	oxidative stress.	1	1	2021
4	chitin oligosaccharide	2	2	2019
	electron beam plasma	2	2	2020.5
	plant biostimulants	1	1	2021
11	seed germination	2	2	2020
	leaf production	1	1	2021

	shoot enlongation	1	1	2021
9	carboxymethyl cellulose	2	2	2017

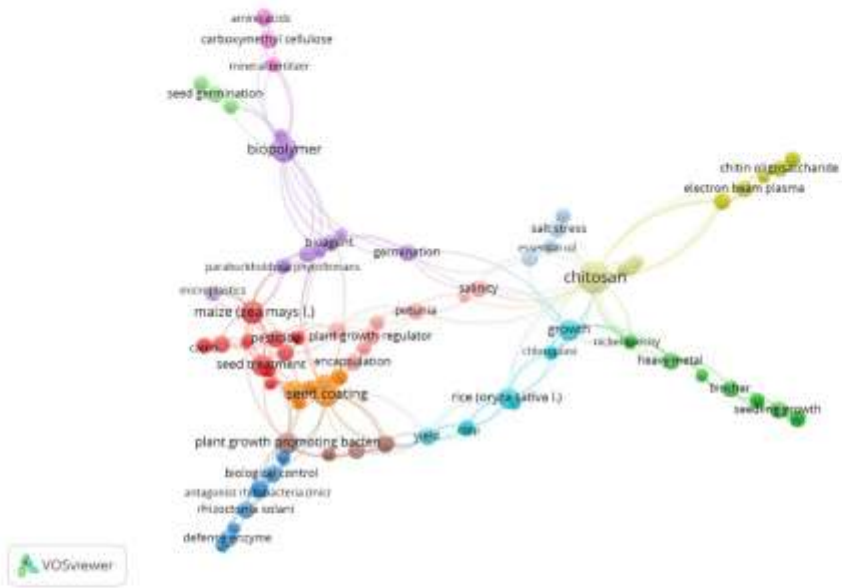

Figure 4.3. Clusters of keywords about renewable alternative materials for the protection of seeds according to their association strength and occurrence.

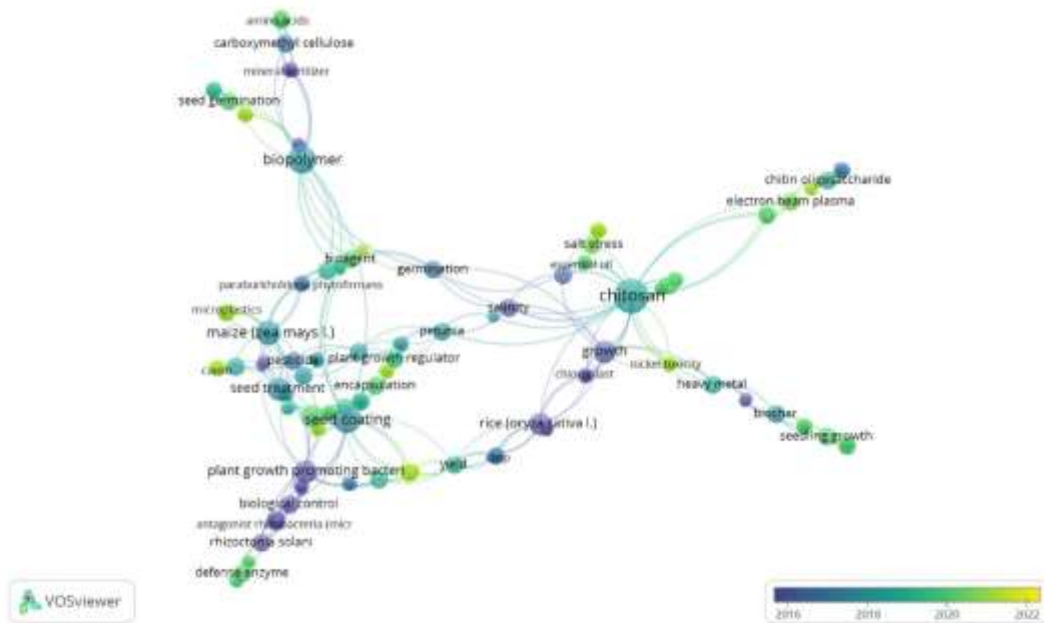

Figure 4.4. Bibliometric network showing the time-lapse for the appearance of keywords about renewable alternative materials for the protection of seeds.

Articles are listed major to minor according to the number of citations in Table 4.3 Choudhary (2017), with a research article concerning biostimulants and biocontrol, occupies first place with 105 citations, approximately 17 per year. Different developments such as coatings (Accinelli et al. 2016; Mahdavi and Rahimi 2013; Chin et al. 2021), containers (Balestri et al. 2019; Flax et al. 2018; Schettini et al. 2013), biocontrol agents (biofungicide, biofumigation and biopesticide) (El-Naggar and Thabit 2014; Jia et al. 2016; Haggag et al. 2007), biostimulants (Winkler et al. 2017; Zhang et al*.* 2020; Hussain et al. 2019) and protect drought agent (He, 2020; Boonlertnirun et al*.* 2007) were observed. In addition, some constituents of the developments were chitosan, starch, biochar's, and natural fibres (Schettini et al. 2013; Rahman et al. 2018; Gascó et al. 2016; Jogaiah et al. 2020; Salachna et al. 2015).

Table 4.3. Applications of renewable alternative materials used for the protection of seeds.

Total of Citations	Citations per Year	Application	Material	Reference
105	17.5	Biocontrol and biostimulant	Cu-chitosan NPs + Chitosan + CuSO4 + commercially fungicide (Bavistin)	Choudhary et al., 2017
68	9.7143	Biocontrol agent for Tobacco mosaic virus	Chitosan oligosaccharide	Jia et al., 2016
49	4.9	Biodegradable pots improving agronomic crop yield	Sodium alginate + Natural fibers from hemp hulls and Strands	Schettini et al., 2013
48	8	Biostimulant	Chitin	Winkler et al., 2017
44	2.75	Biocontrol agent for A. niger	P. polymyxa	Haggag et al., 2007
41	8.2	Biocontrol and biostimulant	Chitosan	Rahman et al., 2018
41	5.125	Plant growth promoter	Oligomeric and polymeric chitosan	Chamnanmanoontham et al., 2015
36	5.1429	Offsetting phytotoxicity for metal nanoparticles	Extracellular polymeric substances (EPS)	Li et al., 2016
35	5	Biostimulant for germination	Biochar I (mixed wood sievings from wood chip production), Biochar II (mixture of paper sludge and wheat husks) and Biochar III (sewage sludge)	Gascó et al., 2016
34	3.4	Seed priming for improving germination, growth and alleviate abiotic stresses	Acetic acid + Chitosan	Mahdavi & Rahimi 2013
31	5.1667	Improving agronomic crop yield	Diazotrophic bacterial (Bacterial strain A. brasilense Ab-V5) + Biopolymer matrix	Oliveira et al., 2017
30	2.7273	Nematicidal activity	Chitosan	Khalil & Badawy, 2012
27	3.8571	Seed coating	Trichoderma harzianum Rifai, Anamorphic + Strain T-22 (ATCC 20847) + Insecticide (imidacloprid) + Fungicide (metalaxyl-M+Starch)	Accinelli et al., 2016

21	7	Improving germination and plant growth in the presence or absence of a fungal pathogen (Fusarium species)	Cellulose acetate + Gelatin from porcine skin+ Acetic acid (695092, ACS reagent), Tween® 80 + Copper (II) oxide nanopowder + Copper acetate monohydrate	Xu et al., 2020
20	6.6667	Stimulating effect on seedling growth	Biochar from rice straw (RS) and wood sawdust (WS)	Zhang et al., 2020
19	6.3333	Antifungal for aflatoxin B1 (AFB1)	Chitosan + sodium-tripolyphosphate + dichloromethane (DCM)+ Glacial acetic acid (GAA) + Dimethyl sulfoxide (DMSO) + Methylglyoxal (MG) + Perchloric acid + Tween-20 + Tween-80 + Silica gel + Ethanol+ Methanol + 2,2-diphenyl-1-picrylhydrazyl (DPPH) + 2,2′-Azino-bis (3 ethylbenzothiazoline-6-sulfonic acid) + Diammonium salt (ABTS)+ PDA and SMKY	Kumar et al., 2020
18	1.5	Biocontrol and biofertilizer agent	Bacillus subtilis microcapsule	Hernández-Suárez et al., 2011
18	6	Seed priming for growth stimulation and pest biocontrol	Chitosan	Jogaiah et al., 2020
17	5.667	Biostimulant	Trichoderma harzianum strain T22 + Biopolymer (Carboxymethyl cellulose and Pluronic)	Carillo et al., 2020
17	3.4	Biocontrol by seed coating	Starch with pesticides (insecticide: imidacloprid; fungicide: metalaxyl-M) and spores of non-aflatoxigenic A. flavus NRRL 30797+ Chitin + Glycerol	Accinelli et al., 2018b
16	1	Chitosan for drought and plant yield recovery	Acetic acid + Chitosan	Boonlertnirun, S. et al., 2007
14	2.8	Biocontrol and biostimulant by seed coating	Modified corn starch + Chitin + Glycerol + Insecticide + Fungicide	Accinelli, C. et al., 2018a
12	3	Seed coating biostimulants, biopesticides, and biofertilizer for yield improvement and seedling strengthening	PVA + PVP + Glycerol + Canola + B. subtilis+ Fungal strains (Macrophomina phaseolina, Rhizoctonia solani and Fusarium oxysporum)	Hussain et al., 2019
11	1.1	Encapsulated seeds	Sodium alginate + Calcium chloride ($CaCl2+H2O$)	Sakhanokho et al., 2013
10	1.6667	Biostimulant	Arabic gum + Carboxymethylcellulose (CMC) + Dextran + Gelatin + Glycerol + Saponin + Xanthan + Alginate, egg lecithin, soy lecithin, skimmed milk + Chitosan (food grade) + Castor oil	Bejarano et al., 2017

10	3.3333	Biostimulant for improving plant tolerance to oxidative stress under salinity	NaCl + Chitosan + Acetic acid + Murashige and Skoog nutrient medium (MS)	Razavizadeh et al., 2020
10	2.5	Seed coating biostimulants for germination and growth	Micronized vermicompost + Defatted soybean meal + Vegetable protein + Diatomaceous earth (DE) + Xanthan gum (XG)	Amirkhani et al., 2019
8	1.1429	Seed coating for improving native plant establishment	Biochar from ponderosa (Pinus ponderosa) and lodgepole (Pinus contorta) pine logs	Williams et al., 2016
7	0.5	Seed priming to improving germination and biocontrol and management of pearl millet downy mildew disease	Gum biopolymers + Metalaxyl (Apron 35 SD)+ Methyl-N-(2-methoxyacetyl)-N-(2.6-xylyl)-DL-alaninat	Sudisha et al., 2009
7	1.4	Growth stimulator	Chitosan	Krupa-Małkiewicz & Fornal, 2018
7	3.5	Seed germination promoter	Chitosan+ Alginic acid sodium salt + Sodium tripolyphosphate (STPP) + Copper(II) oxide nanopowder	Leonardi et al., 2021
7	2.3333	Biofungicide	Chitosan-hexaconazole-dazomet	Maluin et al., 2020,
6	1.5	Germination and biostimulant	Bio-oil derived from algae biomass Macrocystis pyrifera	Sankaranarayanan et al., 2019
5	0.625	Biostimulator	Chitosan	Salachna et al., 2015
5	0.8333	Biodegradable seedling trays improving seedling quality	PLA (polylactic acid)	Shi et al., 2017
4	1	Biocontainer for crops	Posidonia oceanica "egagropilas" fibers + Poly(3-hydroxybutyrate-co-3-hydroxyvalerate) + Acetyl tributyl citrate + Calcium carbonate	Balestri et al., 2019
4	1.3333	Stimulant for seed germination and biomass production	Chitosan + Softwood lignocellulose	Vasilieva et al., 2020
3	0.3333	Reduce Fusarium mycotoxins	b-d-glucan biopolymers	El-Naggar & Thabit, 2014
3	1.5	Promoter seed germination	Chitooligosaccharide (COS)	Vasilieva et al., 2021
3	1	Biocontrol for ShB caused by R. solani	Chitosan + Acetic acid	Divya et al., 2020
2	0.2222	Stimulating effect germination and growth of plants	Xanthan gum + Sodium salt of carboxymethyl cellulose + Fertilizers + Micronutrients	Struminska et al., 2014
2	0.1818	Protection and growth stimulation of seed and seedling	Chitosan + Hemicelluloses (galactoglucomannans)	Niekraszewicz et al., 2012

2	1	Improving Ni toxicity tolerance in soybean	Chitosan	Sadeghipour, 2021
2	1	Seed biopriming	Sodium alginate + Carboxymethylcellulose + Gum arabic + Xanthan gum + Trichoderma asperellum	Chin et al., 2021
2	1	Biocontrol	Biopolymer from the leguminous plant Ceratonia siliqua + T. harzianum M10 + T. atroviride P1 + T. longibrachiatum MK1	D'Errico et al., 2021
2	0.6667	Essential oil-based natural herbicides	Savory (Satureja hortensis L.) essential oil (EO) + Natural polymers (i.e., Arabic gum/gelatin (AGG), apple pectin (AP), gelatin (G))	Taban et al., 2020
2	0.6667	Agent anti-drought	Chitosan oligosaccharide	He et al., 2020
2	0.5	Biostimulant for germination and seedling growth, biopesticide	Chitosan	Zohara et al., 2019
1	0.0667	Seed germination and vigor	Chemical fungicide (CA) + Biological fungicide polymers [chitosan-lignosulphonate polymer (CL) and eugenol incorporated into chitosan-lignosulphonate polymer (E+CL)]	Thobunluepop et al., 2008
1	0.2	Biocontainer	90% polylactic acid (PLA) and 10% lignin, and 60% PLA and 40% soy polymer with adipic anhydride	Flax et al., 2018
1	0.5	Stimulating effect for germination	Chitosan + alginate/PEG + Commercial inoculant (HiStick® Soy)	Jarecki, 2021
1	0.5	Biocontrol for A. thaliana Against Salinity	Bentonite and l-proline	Merino et al., 2021
1	0.5	Stimulating effect for germination and growth plant	Chitosan+ Alginate with PGR (plant growth regulators)	Vlahoviček-Kahlina et al., 2021
1	0.5	Minimizing abrasion losses	Sepiret (BASF, Ludwigshafen Germany) + Starch-based liquid bioplastic + Soy protein	Accinelli et al., 2021
1	0.3333	Growth regulating agent	Zn-chitosan (Zn-CNPs)	Hameed et al., 2020
0	0	Stimulating germination and plant growth under non-stressed and stressed environments	Silk solution + Trehalose and R. tropici grown in Lysogeny broth (LB)	Mhada et al., 2021
0	0	Seedling pots	Cotton + Newspaper + Corrugated cardboard + Polycotton	Juanga-Labayen & Yuan, 2021

0	0	Growth stimulant	N-acetylated (10%) + Chitosan (CHT) + 6-benzylaminopurine (BAP) + Kinetin (KIN)	Premi et al., 2021
0	0	Bionfungicide and seed germination	Neem oil + Tween 20 + High-methoxyl pectin (HMP)+ Ultrapure Water + High-methoxyl pectin (HMP) + Polymer L232	De castro e silva et al., 2020
0	0	Biostimulant for seed germination and increased seedling growth rate	Nanocomposites of HS/Ag	Dolmaa et al., 2018
0	0	Biocontrol and biostimulant	Pseudomonas fluorescens + Rhizobium spp. + Phosphorus solubilising bacteria (PSB) + Bio-friendly polymer + Sugar syrup	Jagadeesh et al., 2019

Authors

Table 4.4 shows the researchers with the highest number of publications in the area in the last 14 yr: Abbas, H.K; Accinelli, C. and Shier, W.T. with four documents each and H indices of 3 and 59 times cited respectively. The H index indicates an estimate of the importance, significance, and broad impact of a scientist's cumulative publications (Hirsch, 2005). Lotka's law revealed that the frequency of publication by researchers was still low, with 93.7% of the authors having just written one document. The evidence shows that the search for the development of alternative materials to improve germination, growth, crop yield and physical and phytosanitary protection of seeds and seedlings, has not received sufficient attention from the scientific community.

Table 4.4. H index of principal authors about renewable alternative materials for the protection of seeds.

Author	Total of publications	Total of citations	H index	Year first published
Abbas, H.K.	4	59	3	2016
Accinelli, C.	4	59	3	2016
Shier, W.T.	4	59	3	2016
Little, N.S,	3	45	2	2016
Rahman, M.	2	43	2	2018
Hameed, A.	1	1	1	2020
Islam, M.T.	2	43	2	2018
Kotowicz, J.K.	2	44	2	2016
Lanzuise, S.	2	19	2	2020
Malinconico, M.	2	51	2	2013

Countries

Considering the scientific production, the result was a network with 33 countries ordered into 17 clusters based on total association strength (Table 4.5). United States was part of the cluster with the highest association strength (10), and contributed with 14 publications and 306 citations, following by Italy with 10 publications and 139 citations. China with only five articles allows 131 citations, just one research have 68 citations the paper was about Biocontrol agent for Tobacco mosaic virus food (Jia et al. 2016). These results suggest that collaborative work in this line of research is still developing.

Table 4.5. Network of international co-authorship about renewable alternative materials for the protection of seeds.

Cluster	Country	Documents	Citations	Total link strength
2	United States	14	306	10
2	Bangladesh	2	43	2

9	Italy	10	139	5
3	India	6	158	3
1	Germany	2	49	2
1	Spain	2	83	2
1	Thailand	3	58	1
5	Russian Federation	3	7	2
6	Egypt	3	77	1
8	Iran	4	48	1
13	China	5	131	0
16	Poland	4	15	0

4.5. Conclusion

According to our results, production and collaboration between researchers and countries on the development of new materials to improve the quality of seeds is still emerging. Individual production and global and interdisciplinary collaboration are required to develop, test and apply new and existing materials to improve the quality of seeds with the aim of reducing pollution and raw material depletion.

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4.8. Conflicts of Interest

The authors declare no conflict of interest.

5. CONTAMINATION OF AGRICULTURAL SOILS BY PLASTICS: A SYSTEMATIC REVIEW WITH A BIBLIOMETRIC ANALYSIS

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5.1. Abstract

Purpose: To guide researchers and practitioners from various knowledge areas to identify information gaps by identifying, analyzing, and synthesizing the published research about the contamination of agricultural soils by plastic featuring the most prolific authors and the influential scientific papers that have been published

Research method: This paper presents a systematic review with a bibliometric analysis; the search was made on the SCOPUS® and Web of Science ™ databases up to September 2021. Subsequently, a selection of articles according to the criteria of inclusion and exclusion was carried out and, using bibliometric indicators, VOSviewer v. 1.6.15 and bibliometrix v. 3.0 software, information was obtained to answer the research questions

Findings: Results indicate that the number of articles on this topic is still emerging nevertheless, there has been an increase in the number of publications due to the global concern for conserving the environment, with twenty articles in 2021. Contributions concentrate on a few sources of contamination such as agricultural activities (mulching film), irrigation with treated wastewater, and application of biosolids. The most prolific country is China, with 28 articles. Geissen, V., is the researcher with the most outstanding contribution and permanence with seven documents and an H index of six.

Research limitations: The analysis was done employing the SCOPUS® and Web of Science ™ database, moreover, the worldwide production of articles is changing every day. Also, some information could be discarded not being available in these bibliographic resources.

Originality/value: The systematic review gives a clear overview of the knowledge and the development of a topic; the conclusions are based on the evidence and can be helpful to establish a groundbreaking for future investigations.

Keywords: agricultural activities; China; mulching film

5.2. Introduction

The piece of plastic debris fragment into smaller pieces and decompose in long-lasting periods, up to hundreds of years persisting in the environment (Zhang et al. 2018; Khalid et al. 2020). On the overdependence on non-renewable resources to achieve the required levels in the production of food (Lin et al. 2009) the most used tools are plastics, which can produce the most ubiquitous and long-lasting changes on the earth's surface (Barnes et al. 2009). Of all the anthropogenic changes on the earth, microplastic pollution is probably the most relentless (Khalid et al. 2020). Plastics are transported into environments by wind (Rezaei et al. 2019; Beriot et al. 2021) and water (Horton et al. 2017; Xie et al. 2020). Also are classified by particle size ranging from plastics (>25 mm) (De Souza Machado et al. 2018; Xie et al. 2020; Yu, L. et al. 2021), to mesoplastics with a size of 5 to 25 mm (Yu, H. et al. 2021), microplastics <0.5 µm (Silva et al*.* 2018; Ambrosini et al. 2019), and nanoplastics <0.1 µm (Revel et al. 2018; Wang, F. et al. 2020).

Microplastics are cataloged as primary (manufactured by applications) and secondary plastics (resulting from fragmentation or degradation from large plastics) (Khalid et al. 2020; Zhang, Y. et al. 2020). The major pathways by which microplastics are introduced into agricultural soils are fertilizer application, sludge from water treatment plants, urbanization, irrigation with wastewater (Lü et al. 2018); soil amendments, compost, plastic mulching (Bläsing and Amelung 2018), greenhouse covers (Blöcker et al. 2020) and roads (Kibblewhite 2018).

Plastics are considered contaminants with the potential to enter terrestrial environment, affecting the soil quality, health, and functionality (Snow et al. 2019) among the interactions, acting as a vector of substances like heavy metals, phthalic acid esters (PAEs), inorganic and organic/ chemical material (Khalid et al. 2020; Harms et al. 2021). Also, plastic formulations contained plasticizers and flame retardants categorized as carcinogenic, teratogenic, and mutagenic (Bai et al. 2020; Yan, X. et al. 2020). Furthermore, must be made clear that contamination is the existence of an element where it should not be or at concentrations above the background (Chapman 2007). Pollution is the result of contamination causing adverse effects in the communities, that is to say, the pollutants are contaminants, but not all contaminants are pollutants (Chapman et al*.* 2003).

Hence the contamination of agricultural soils by plastics is an urgent theme because of the impact on the environment and human health by entering the chain of food (Zeng et al. 2020; Beriot et al. 2021; Wanner 2021). Thus, the current systematic review aims to identify, classify, and examine the most reliable, relevant, updated papers and realize a bibliometric analysis to illustrate the most productive authors, countries, sources of contamination, and the characteristics of the relevant documents of a scientific field.

5.3. Metodology

In this article, a systematic review with bibliometric analysis was conducted. A systematic review defines as a summary of the existing literature, finding the focus, trends, and issues of current research (Meredith et al. 1993; Dora et al. 2020). Used for identifying, evaluating, and interpreting all available research with a reproducible design, synthesize the studies published to answer specific questions related to a particular topic area or phenomenon of interest (Budgen and Brereton 2006; Konur 2012; Thomé et al. 2016). Bibliometric analysis is a quantitative method that measures citation researchers, institutions, research teams, and countries. Analyzing and identification national and international networks to map the development of new (multi-disciplinary) fields of science and technology, works for scholarly journals, books, and researchers (De Montis et al. 2017; Shonhe 2020).

Systematic review

There are several methodologies for conducting a systematic literature review (Budgen and Brereton 2006; Thomé et al. 2016; Seuring et al. 2012; Mascarenhas et al. 2018; Baraibar et al. 2020). The most studied are those around medicine with the PRISMA approach (Urrútia and Bonfill 2010), the methodology used in this article is the proposed by Koutsos (2019) consisting of 6 steps: **(1) Scoping; (2) Planning; (3) Identification; (4) Screening; (5) Eligibility/ Assessment, and (6) Presentation**.

Step 1. Scoping (Planning the Review and defining an overall research aim and preparing the protocol)

After identifying a gap in the research field, it is vital to establish detailed, clear, and reproducible guidelines. To fulfill the objective a set of research questions (RQ) was elaborated by the participants of the working group: RQ1. How has research progressed in a study in terms of scientific publications and citations? RQ2. Who are the researchers with the highest number of scientific reports? What was their citation impact? RQ3. What country has the most outstanding production of scientific articles related to the subject of study? RQ4. What are the most important sources of contamination by plastics?

Step 2. Planning (Identifying database, search strategy and criteria of eligibility)

The bibliographic search stage was made using the SCOPUS® and Web of Science ™ databases, these databases are the most complete digital source of scientific articles with peer-review journals with rigorous selection criteria for publishers and the most used in the bibliometric analysis (Sweileh et al. 2018; Koutsos et al. 2019). Initial keywords searched were directed towards answering the main objective and research questions. First, to avoid bias, general concepts were searching, those related to the classification of plastics by size. Subsequently, were used specifics concepts to guide the search within the agricultural area with the logical boolean operators "AND" & “OR” (Maçaira et al. 2018), the search was updated in September 2021. The set of general and specific keywords used was: *“((plastic) AND (“agricultural soil” OR “agricultural land” OR cropland OR farmland OR "farming land") AND ("soil pollution" OR contamination OR "white pollution" OR "agricultural waste" OR "waste hazardous" OR "anthropogenic contaminants" OR "hazardous pollutant" OR "hazardous contaminant" OR "hazardous substances"))”. With combination of ("mesoplastic" OR "meso plastic”) ("microplastic” OR “micro plastic") ("nano-plastic” OR “nano plastic")* instead of *“plastic”* in the Scopus database was made in *“TITLE-ABS-KEY”* and Web of Science in *“TOPIC”.* Furthermore, a clear and specific criterion of exclusion and inclusion needs to establish. In this context, considerations as made as follows only considered documents such as "article research" without restriction on the year of publication, language, or research area. For thematic, only those based on the research of quantification and identification of particles plastics in agricultural soils.

Step 3. Identification of articles for the study

This initial search yielded a total of 415 references. Identification and removal of 168 duplicate references left only 247 working documents. The latest search was updated in September 2021. Subsequently, the remaining articles were chosen randomly and numbered consecutively. Two different collaborates independently read the title and abstract of the articles. Articles were first read in descending order and then in ascending order to minimize errors. Discrepancies, in the opinion of the readers, were solved with the intervention of a third. Only 113 documents remain after this step, excluding 134 references. The documents excluded do not follow the inclusion criteria. Following the previous procedure, each remaining article was reading entirely to discard those outside the study subject 65 references. Finally, 48 articles remained, obtained a matrix comprising all the documents for the bibliometric analysis, this information presents following the PRISMA flowchart (Figure 5.1)

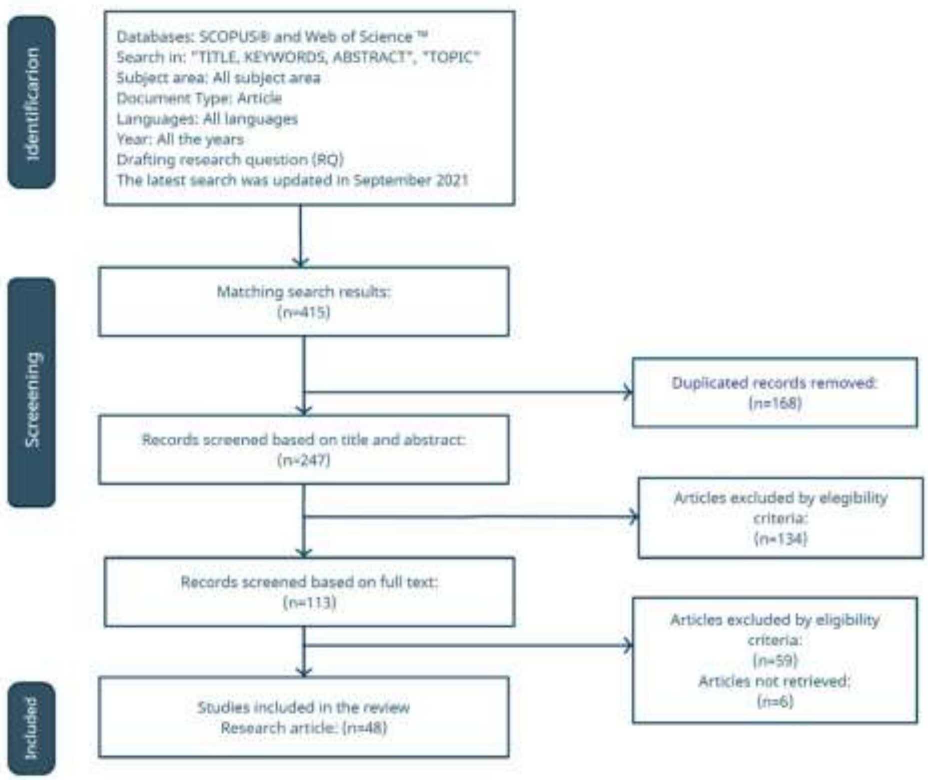

Figure 5.1 Stages of Systematic Literature (Author's elaboration, modified from Urrutia and Bonfill (2010))

The articles considered in the systematic review accomplish the inclusion criteria, and it is crucial to establish the validity of the information according to the support contained in these. As follows, assigned a level of support ***(I)* Substantiated:** for articles with identification, extraction, and quantification of plastic particles by validated methods, **(II) Partially substantiated**: Identification and quantification by experimental methods, and **(III) Unsubstantiated**: only identification of plastic particles.

Step 4. Screening

Before obtained the final matrix of information for bibliometric analysis, it is necessary a data cleaning. Duplicate and misspelled elements need to check, different spellings of an author's name, in the keywords the synonyms, abbreviations, or duplicate elements (Aria and Curcullo 2017) and were made in an Excel® spreadsheet.

Step 5. Eligibility/ Assessment

To minimize bias and ensure the quality of the articles included in this study, they are carefully analyzed and assigned a level depending on the evidence they present: **Strong (III)** includes point sources of contamination, analytical methods for extraction, and identification of plastic shape and plastic-type.

Moderate (II) inconclusive or inferred source, for the visualization dynamic or mathematical model, artificial vision, images, and identification of plastic shape or plastic-type. **Low (I)** inferred point source, theoretical estimates, and not included plastic shape or plastic-type.

There is a risk of bias in this review, the most relevant databases were reviewed, some articles can exclude as they are not included in them, as well as those scientific papers that did not reach the publication stage but contain relevant information for this study (Koutsos et al., 2019) considering that the global output of research articles changes every day.

Bibliometric analysis

Bibliometric analysis is a quantitative method, that includes mathematical and statistical methods. Utilizing specific indicators to obtain information regarding the output of research activity from written publications, examine the knowledge structure and development in the research, to know whether there are connections among authors, countries, and identify emergent and influential topics and, point out gaps in the subject (Romero and Portillo 2019; Baraibar et al. 2020; Fortuna et al. 2020). Was conducted with the R-tool for Bibliometrix 3.0 software: Biblioshiny (Aria and Curcullo 2017) and VOSviewer version 1.6.14 used for the network visualization map. The software measures the strength of the relation between two elements based on the separation distance through an optimization technique, forms clusters from a set of tightly related nodes, the node size is proportional to the number of occurrences (www.vosviewer.com; (Van Eck and Waltman 2009). With Biblioshiny was obtained the Annual Scientific Production that measures though years how many articles have been published. The author´s scientific production over the time was determined in terms of the number of publications (Aria and Curcullo 2017), Lotka´s law and H index also were calculated. Lotka´s law is an approximate inverse-square law where the number of authors publishing a certain number of articles is a fixed ratio to the number of authors publishing a single paper (Elango and Rajendran 2012). H index measures the broad impact of an individual's work and avoids the disadvantages of other criteria it provides an objective measurement of the impact and relevance of an author's academic works (Hirsch 2005).

The software VOSViewer generates maps to evaluate the relation between terms related to researchers, institutions, and keywords (Krauskopf 2018) on the topic. Bibliometric indicators such as bibliographic coupling, co-authorship, and co-occurrences can be obtained, with authors, countries, and all keywords as the unit of analysis. VOSviewer gives equal weight to co-authorship, and citation of a publication ("fractional counting") regardless of the number of authors, citations, or references thereof (Perianes-Rodriguez et al. 2016).

5.4. Results

The information obtained from the 48 articles, published between 2006 and 2021was obtained by the systematic literature review and gathered in the final matrix (Table 5.1). On average, each article has been cited 57 (57.1) times and written by five authors (4.73). The collaboration index (CI) is 4.76 (Elango and Rajendran 2012). The most influential sources are Science of the total environment (n=18), Environmental pollution (n=8), and Journal of hazardous material (n=3) these three journals are ranked in the best quartile (Q1) according to SCImago Journal Rank (SJR) 2021 (www.scimagojr.com/journalrank.php).

Description of results

Table 5.1 Main information of articles about contamination of agricultural soils by plastics

Description of results	**Results**
Period of years of publication	2006-2021
Occurrence of journals	19
Number of documents	48
Years between each publication[1]	2.4
Number of citations of each article[1]	57.1
Number of citations of each document per year[1]	15.45
Number of the total of references	1,993
Research articles	48
Total number of phrases that frequently appear in the title of an article´s references	815
Number of keywords	141
Number of authors	227
Articles with a single author	0
Articles with multi-authored articles	227
Number of documents by an author1	0.211
Number of authors by document1	4.73
Number of co-authors for each article	5.6
Collaboration Index	4.73

[1]Average

Scientific production

The first and only article recorded in 2006, finding residues of low-density polyethylene (LDPE) film in agricultural soils from agricultural activities (Xu, G. *et al.,* 2006) Analysis by the bibliometrix R package shows that field has an 82.06% annual growth rate (Agbo et al., 2021) of scientific production (Figure 5.2). In 2018, six articles were recorded, which indicates the beginning of the growth of publications in the field. This growth became higher in 2021, when twenty papers were published, making the highest number of articles per year recorded so far. The research theme of the contamination of agricultural land by synthetic plastics is still emerging and weak in quantity compared magnitude of environmental pollution. Are expected, as revealed from the outcome of the analysis, that the scientific contribution would keep growing yearly.

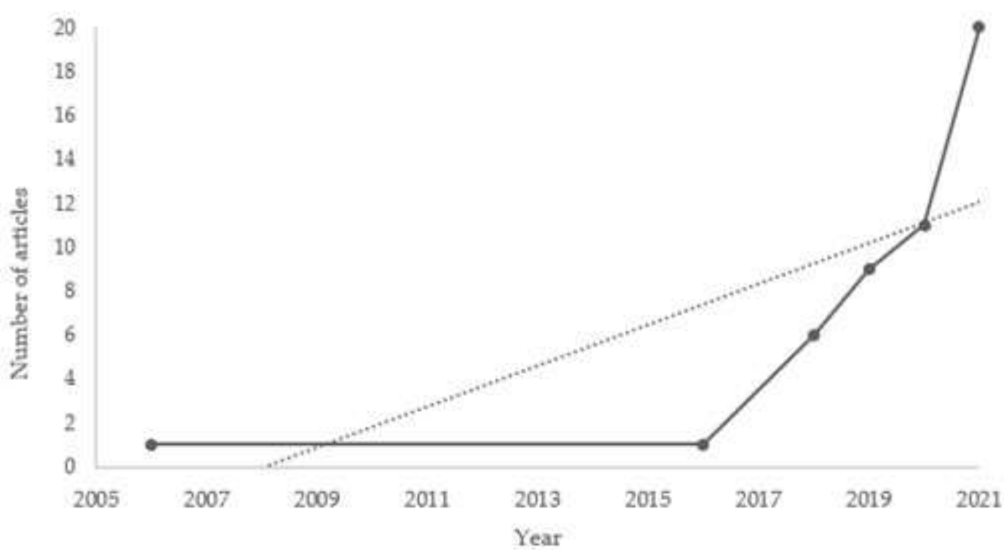

Figure 5.2 Papers published between 1979 to the middle of 2021 about the research field. (R-tool for Bibli-ometrix: Biblioshiny, 2022)

Authors

To know the most prolific authors, was measured the author production over the time, the H index and, Lotka´s Law. For the H index measure, were included the 10 principal authors. Table 2 depicts the ranking of authors by H index. Geissen V. suggested being the most impactful author in the field with seven publications, an H index of six, cited 701 times, and first published in 2018. Followed by Huerta Lwanga E. and Yang Y. Geissen V. and Huerta Lwanga are frequent co-authors in the investigation of contamination of agricultural soils (Corradini et al. 2019).

Table 5.2 Main information about data obtained by systematic literature review

Author	H index	Citations	Publications	First year publication	Institution
Geissen, V.	6	701	7	2018	Wageningen University & Research
Huerta-Lwanga, E.	5	444	5	2019	Wageningen University & Research
Yang, X.	3	582	4	2018	Wageningen University & Research
Corradini, F.	3	415	3	2019	Instituto de Investigaciones Agropecuarias (INIA)
Luo, Y.	2	144	3	2020	Chinese Academy of Sciences
Casado, F.	2	316	2	2019	Instituto de Investigaciones Agropecuarias (INIA)
Fan, B.	2	47	2	2018	Pennsylvania State University
Fei, Y.	2	116	2	2020	Zhejiang Agriculture and Forestry University
Gu, X.	2	84	2	2019	Nanjing University
Guo, L.	2	47	2	2018	Sichuan University

Over the time, Geissen V.; Huerta Lwanga E.; Yang X.; and Corradini F. are the researchers with the most outstanding contribution and permanence in the same research area with seven, five, four, and three publications, respectively. The intensity of the color is proportional to the total citations per year and, the size of the bubble represents the number of documents per author (Figure 5.3). Through Lotka´s Law, it revealed that the frequency of publication by researchers is weak 86.8% of the total of authors just have written one document. This analysis and the indicators below observed that the most cited and prolific authors are Geissen V.; Huerta Lwanga E. and Yang X.

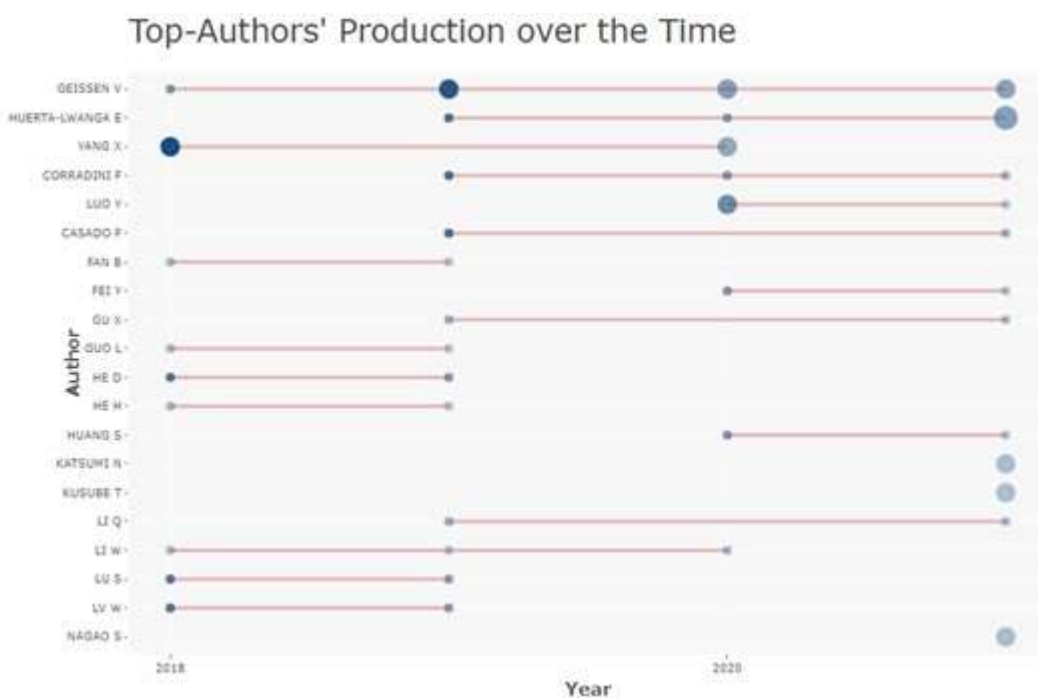

Figure 5.3 Top author´s production over time in the topic related to contamination of agri-cultural land by plastics (R-tool for Bibliometrix: Biblioshiny, 2022)

Countries

This section analyses the diffusion of the research field between countries and their collaboration network. Bibliographic coupling occurs when two documents have at least one reference in common (Fusco et al. 2020), the greater the number of matching references between two papers, the higher similarity and therefore the connection between them, which means the interactions among countries (Van and Waltman 2014; Curcullo et al. 2016; Baraibar et al. 2020;). This analysis considers a minimum scientific production of one article per country, the result was a network with 21 countries ordered into six clusters based on total association strength (Figure 5.4).

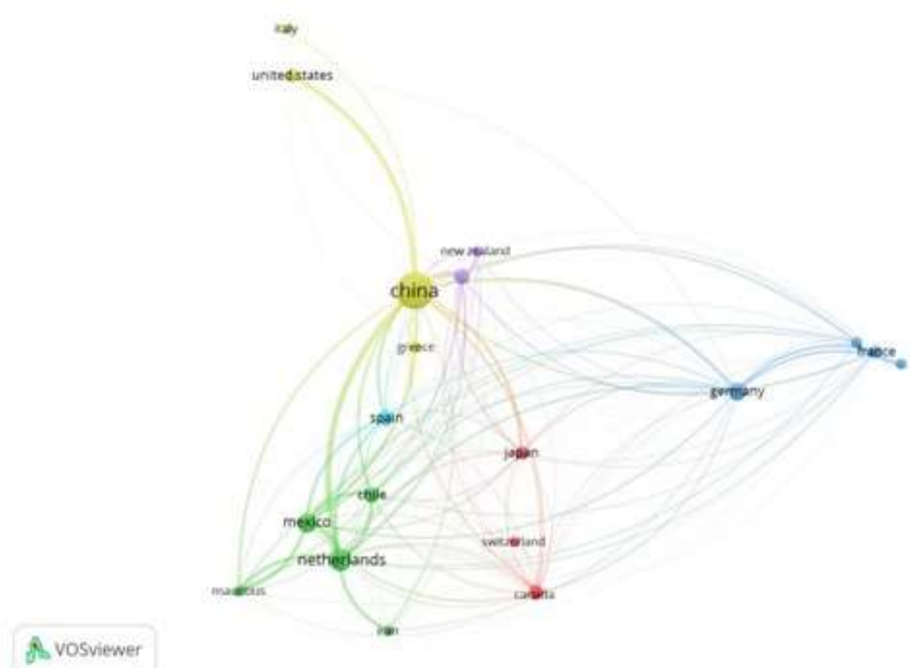

Figure 5.4 Bibliometric network of countries related to contamination of agricultural land by plastics, each color represents a different cluster (VOS Viewer, 2022)

China´s leading countries in the research field, with the highest association strength of 502.50, twenty-eight publications, and 1824 citations. In the second cluster, the leader is Netherland (414.84 association strength, eight articles, and 706 citations) also this cluster contains Mexico, Spain, Chile, and Ira whose´s work is in the detection, effects, impacts, and sources of plastics in agricultural land. However, Germany, with four articles, achieves a low association strength, probably due to affinity (120.49) in publications with countries that scientifically contribute little to the subject (Van and Waltman 2009).

Emergent themes

Aim to answer the research question; Table 5.3 lists the titles, the number of citations, and the principal source(s) of contamination reported in the 48 articles obtained from the systematic literature review. Several sources of contamination are researched, like agricultural plastic, plastic mulch, and sewage sludge (used as fertilizer). The most cited article, with 202 cites, published in 2018, mentions that sewage sludge is a source of entry of plastics into agricultural soils (Rocha-Santos 2018).

Table 5.3 Principal sources of contamination

Citation	Principal source of contamination	Plastic-type (MAPs/MEPs)	Plastic-type (MPs)	Plastic shape	Number of particles detected MPs	Evidence*	Strength of evidence**
(Ragoobur et al., 2021)	Agricultural activities		Polypropylene (PP) (56.26%), Polyamide (PA) (28.71%), Polyethylene (PE) (10.17%), Polystyrene (PS) (2.70%) and Ethylene-vinyl acetate (EVA) (2.16%)	Fibres 64% (shallow) and 73% (deep)	Site 1,2 and 3: 73.3 - 293.3 particles.kg^{-1} (mean = 150.5 ± 90.9 particles.kg^{-1}) (shallow 0-10 cm) and 80 - 433.3 particles.kg^{-1} (mean = 180.0 ± 123.3 particles.kg^{-1}) deep soils (10-20 cm). Site 3:166.7 ± 112.2 (shallow) and 326.7 ± 150.8 particles.kg^{-1} (deep), Site 2: 96.7 ± 33.0 (shallow) and 83.3 ± 4.7 particles.kg^{-1} (deep)	+++	I
(Boughattas et al., 2021)	Irrigated with treated wastewater (TWW)		PE (dominant type), Polybutylene adipate terephthalate (PBAT), EVA, PP and Polylactic acid (PLA)	Fibers (75%) and fragments	S1: Control soil 13.21 ± 0,89 item kg^{-1}; S2: Mulching 475.89 ± 64,29 item kg^{-1}; S3: Soil under greenhouse 411.26 ± 62,68 item kg^{-1}; S4: (TWW) 852.24 ± 124,24 item kg^{-1}.	+++	I
(Cao et al., 2021)	Traffic activity of the roads, surface runoff, sewage, and the atmospheric input		(PP) 62%, (PE) 16%, Rayon 15%, Lowdensity polyethylene (LDPE), (PS),	Fragment (49%), fiber (44%) and film (7%)	Ranged from 4.94 to 252.70 items/kg, mean of 37.32 items/kg	+++	I

		nitrocellulose (CN) and (PA) were also detected but not prevalent				
(Mo et al., 2021)	Agricultural activities (plastic gauze)	Assumed PE	Assumed film	MPs 1629.68 tons	++	II
(Brandes et al., 2021)	Sewage sludge as compost, as well as plastic film			50th percentile (median, kg ha^{-1}) Sewage sludge 0.72, Compost 0.26, Tarps and mulch films 0.03	+	III
(Peñalver et al., 2021)	Agricultural activities	Polystyrene	Polystyrene	Range 33.45 ± 0.01 to 39.40 ± 0.02, average 35.97 ng m^{-3}	+++	I
(Katsumi et al., 2021)	Agicultural activities (Coated fertilizers)	PE	Microcapsules	70% in 2018 or before, 29% in 2019, and 1% in 2020	+++	I
(Isari et al., 2021)	Agricultural activities (Black agricultural mulch film)	PE	Fragments	Fields with watermelon 189 ± 57 to 556 ± 8 with an average 301 ± 140 item kg^{-1}- Canning tomatoes ranged 40 ± 20 to 140 ± 19 (69 ± 38 item kg^{-1})	+++	I
(Feng et al., 2021)	Agricultural activities (Mulching film)	Shallow soil: PE (48.31%), PA (23.53%), PS (7.84%), PP (5.88%) and Deep soil: PE (56.41%), PA (16.3%), PS (8.69%), PP (9.78%)	Shallow soil: Films (36,08%), fibers (24.31%), fragments (22.35%), foams (10.98%), and spherules (6.27%). Deeper soil: Films (40.69%),	Ranged 0 to 260 items/kg. In average on shallow soil 53.2 ± 29.7 and in deep soil 43.9 ± 22.3 items/kg	+++	I

			fragments (27.45%), fibers (20.58%), foams (7.35%), and spherules (3.92%)			
(Li, Q. et al., 2021)	Agricultural activities (including soil amendments, plastic mulching, irrigation, and atmospheric deposition and sewage sludge)	(PE), (PP), (PS), (PA), Polyethylene terephthalate (PET), Polytetrafluoroethylene (PTFE), polyvinyl chloride (PVC), and EVA copolymer		SG 1000–3786 pieces/kg, XZ 1300–3400 pieces/kg	++	I
(Fei et al., 2021)	Irrigated with treated wastewater (TWW), agricuktural activities (compost sludge and black agricultural mulch film)	(PE), (PP), polyester, nylon	Films, fragments and fibers	Range 20 to 1560 microplastics/kg mean 443 microplastics/kg	+++	I
(Choi et al., 2020)	Agricultural activities (mulching and vinyl films)	PP and PE	Fragments (66.1%), film (19.2%), fibers (14.6%), and spheres (0.2%)	664 ± 83 pieces kg^{-1}	+++	I
(Katsumi et al., 2020)	gricultural activities (Microcapsules from coated fertilizer)	PE	Microcapsules	Range 6 to 369 mg/kg, mean 144 mg/kg	+++	I
(Harms et al., 2021)	Agricultural activities	(PE) (87%, 329 particles), (PP) (4%, 14 particles), nylon (3%, 10 particles) and	Foil 61% (232 particles) , fragments 28% (105 particles), and 10% (37	Ranged from 0 to 217.8 MP per kg dry weight (DW), 3.7 ± 11.9 per kg (DW)	+++	I

		(PA)(3%, 10 particles). In small proportions (1–4 particles), polyvinylidene flouride (PVDF), polydiallylphthalate (PDAP), polymethyl methacrylate (PMMA), (PET), polyvinyl formal (PVF), poly(1.4-Butylene Adipate), polyvinyl acetate (PVA) and polyvinyl stearate (PVS)	particles) platelets and fibres (1%)			
(Yu, L. et al., 2021)	Agricultural activities	PP&EPC (45.0%), PE (39.7%), PS (7.9%), PES (2.1%), cellophane (1.7%), PU (1.7%), rayon (1.2%), ABS (0.4%), and polymethyl methacrylate PMMA (0.4%)	Fragments (46.3%), film (25.4%), fiber (15.1%), pellet (12.8%), and foam (0.4%)	Ranged 310 to 5698 items/kg, mean 1444 ± 986 items/kg and median: 1229 items/kg	+++	I
(Beriot et al., 2021)	Agricultural activities (Mulching film, compost by sewage sludge and heces)	Not reported	Not reported	MPs 2116± 1024 particles·kg^{-1}	++	II
(Kim et al., 2021)	Agricultural activities (GS-out (Greenhouse-film-out),MS (mulch-film	GS-in (Greenhouse-film-in use soil) PE	GS-in PE-fragment (80%), Gsout PP-fiber	GS-in (average ± standard deviation = 1880 ± 1563; a median	+++	I

	use soil), agricultural film, GS-in (Greenhouse-film-in use soil), RS (rice-paddy soils)), surface-runoff water and air		(68%) > PET (15%) > PP (11%). GS-out (Greenhouse-film-out use soil) PP (40%) > PE (27%) > PET (20%). MS(mulch-film use soil) PP (31%) > PE (21%) > PET (10%) , and RS (rice-paddy soils) PE (61%) > PP (18%) > PET (9%)	(37%) > PP-fragment (19%) > PE-sheet (18%) > PET-fiber (13%), MS PP-fiber (20%) > PS-fragment (17%) > PE-sheet and PET-fiber (10% for each), RS PE-sheet (31%) > PE-fragment (26%) >PP-fragment (10%)	= 2110 items kg^{-1}), followed by GS-out (1302 ± 2389; 310 items kg^{-1}), RS (160 ± 93; 153 items kg^{-1}), and MS (mulch-film use soil) (81 ± 77; 65 items kg^{-1})		
(Wang, J. et al., 2021)	Agricultural activities (mulching film) and surface irrigation		(PE) 20.88%, and (PA) 20.31%, Polyester (12.51%), PS (11.38%), PP (10.82%), PVC (7.84%), acrylic (6.19%), and others (10.08%)	Fragments (54.40%), fibers (26.88%), films (10.19%) and spheres (8.53%)	3910 ± 1031 items/ kg (wheat land), 5490 ± 573 items/ kg (paddy land), 3683 ± 362 items/ kg (woodland), 3386 ± 593 items/ kg (orchard land), 5386 ± 835 items/ kg (mulch film soil), and 5124 ± 632 items/ kg (greenhouse soil)	+++	I
(Corradini et al., 2021)	Agricultural activities		Acrylates, polyurethane, and varnish (most common), Polyethylene was the second most common , followed by PE was the second most common , followed	Fiber (68%), films (23%), fragments (7%) and pellets (2%)	Crop lands 306 ± 360 particles kg^{-1} and pastures 184 ± 266 particles kg^{-1}	+++	I

			by PP, nitrile rubber, and polystyrene				
(Zhang, Z. et al., 2021)	Agricultural activities (Mulching film)		Not reported	Fibers (23.76%–30.74%), films (33.96%–40.06%), pellets (11.81%–14.60%), fragments (10.91%–24.20%), and foams (4.71%–6.28%)	646.67 ± 45.09 to 2840 ± 155 items/kg	++	I
(Li, W. et al., 2020)	Agricultural activities (Mulching film)		PE	Fragments and fibers	From 5 to 30 years range of 10.10–61.05 mg/kg	+++	I
(Meng et al., 2020)	Agricultural activities (Mulching film)	MaPs 6–8 years (97.4kg·ha−1) to 30 years (53.7 kg·ha−1)		Fragments	MPs with intermittent mulching in S1 up to 2,200 particles·kg^{-1} soil and in S2 were detected up to 900 particles·kg^{-1} soil	+++	I
(Weber et al., 2020)	Land use and fluvial processes	Floodplain soil: MEP 2.06 kg^{-1} (±1.55 kg1) maximal values of 5.37 MEP kg^{-1}	MEPs: 5 PE-LD with 5 particles, CMP: 16% of PE-LD in CMP fraction PP (6%), PA (5%), PS (4%), POM (4%) and PET (3%)	Fragments (32%), films (32%), filaments (19%) and "fiber balls" (11%)	Floodplain soil: coarse microplastics (CMP) 1.88 kg^{-1} (±1.49 kg^{-1}) maximal value 8.59 CMP kg^{-1}	+++	I
(Crossman et al., 2020)	Agricultural activities (Compost by biosolids)		Polyester	Fibers (41–45%)	Field 1: 25 ±20.8% MP kg^{-1} ,Field 2: 130 ±23.1% MP kg^{-1},Field	+++	I

					3: 298 ±39.1% MP kg^{-1}		
(Ding et al., 2020)	Planting type of soil and climatic factors		PS), (PE), (PP), high-density polyethylene (HDPE), (PVC) and (PET)	Film, fiber, fragment and pellet	1430 to 3410 items/kg	+++	I
(Vaan den Berg et al., 2020)	Agricultural activities (Compost by sewage sludge)		(PP) and (PVC)	Fiber, fragment or film	2130 ± 950 kg^{-1} light density and 3060 ± 1680 heavy density kg^{-1}	+++	I
(Huang , Y. et al., 2020)	Agricultural activities (Mulching film)	MaPs 83.6 kg/ha	LDPE	Films	MPs 5 y: 80.3 ± 49.3 pieces/kg soil, 15 y: 308 ± 138.1 pieces/kg soil, and 24 y: 1075.6 ± 346.8 pieces/kg soil	+++	I
(Zhou et al., 2020)	Agricultural activities (Mulching film)		Films: (PE), co-polymer with (PP) (75%) and nylon. Fragments: PP, co-polymer with PE (60%), PE (10%). Fibers: PE, PP and their co-polymers (15%) in the fibers, Rayon (41%) and polyester (33%), acrylic and (PA) (10%)	Films , fragments and fibers	MPs Mulching soil: 571 pieces kg-1 Non mulching soil: 263 pieces kg-1	+++	I
(Zhang, L. et al., 2020)	Agricultural activities (Compost by sewage sludge)		PE (18.3%), PP (59.2%), PET (17.9%), PP/PE (0.4%), PB (2.9%), and EVA (1.3%)	Field A flakes (85.9%), fibers (12.5%), and films (1.6%), field B films (50.3%),	MPs Field A 545.9 ± 45.7 items/kg, field B (87.6 ± 9.3 items/kg) and field C (5.0 ± 0.4 items/kg)	+++	I

				fibers (31.2%) and flakes (18.5%) and field C flakes (29.05%) and fibers (71.0%)			
(Zhang, S. et al., 2018)	Surface soil water loss (>96%) infiltration through soil pores (<4%)		PE	LDMP	Site A: (45.74726N, 126.74980E) 0–8400 N kg^{-1} (mean 107 ± 178 N kg^{-1}), Site B: (45.74735N, 126.74990E) 0–400 N kg^{-1} (mean 100 ± 100 N kg^{-1}), 0–1400 N kg^{-1} (mean 400 ± 692 N kg^{-1}) depth 0–20 and 20–30 cm respectively, Site C: (45.74515N, 126.89242E) 0–400 N (mean 100 ± 173 N kg^{-1}) and Site D: (45.74222N, 126.90075E) 0–200 N kg^{-1} (mean 50 ± 87 N kg^{-1})	++	II
(Chen, Y. et al., 2020)	Agricultural activities, large traffic flow and domestic wastes		(PA) (32.5%), (PP) (28.8%), (PS) (16.9%), (PE) (4.2%) and (PVC) (1.9%)	Microbeads (48%), fibers (37%), fragments (15%) and foams (1%)	Ranged from 320-12560 items/kg dry weight (DW), with mean concentration of 2020 items/kg DW	+++	I
(Kalberer et al., 2019)	Agricultural activities	MAPs/MEPs	PE	Silo bale film (6000±800 t a^{-1}), greenhouse/weather protection		+	III

			film (3000±800 t a^{-1}), tape fabrics (500±100 t a^{-1}) and PE mulching films (300±100 t a^{-1}), (3000±800 t a^{-1}).			
(Li, Q. et al., 2019)	Agricultural activites	PE and PP	Fibrous dominate following by bulk and fragment	420-1290 items/kg	+++	I
(Zhang, J. et al., 2019)	Agricultural activites (Mulching film)		Films	In 2016: 121.85, 215.85, 250.63, 294.17, 327.83, and 352.38 kg ha^{-1}, increased by 18.92, 16.75, 16.59, 17.82, 19.25, and 16.95 kg kg ha^{-1} in 2017	++	II
(Xiong et al., 2019)	Agricultural activites (Mulching film)		Films	Plastic-mulched farmland mapping algorithm (PFMA) and imagery with the classification and regression tree (CART) accuracy of 92.2% with a producer's accuracy of 97.6% and a user's accuracy of 86.7%, and the F-score was 0.914 for the PMF class	+	II
(Corradini et al., 2019)	Agricultural activities (Compost by sewage sludge)		Fibers (97%)	1 application (median 1.1 particles g^{-1}), 2 application (median	++	I

					1.6 particles g^{-1}), 3 application (median 1.7 particles g^{-1}), 4 application (median 2.3 particles g^{-1}), and 5 application(median 3.5 particles g^{-1}) dry soil		
(Rezaei et al., 2019)	Wind erosion		LDPE	Microplastic particles	Ranged 67 to 400 particles per kg	+++	I
(Hao et al., 2019)	Agicultural activities (White agricultural mulching film)			White films	Workflow merging PML of multiple temporal phases (MTPML), PMLI_SWIR approach has best PML identification performance (OA equal to 89.25%)	++	II
(Lv et al., 2018)	Hydrodynamic conditions and agicultural activities (organic fertilizer and commercial fish diets)		PE (61.4%), PP (35.1%) and PVC (3.5%)	Fiber and fragment	61 items, rice soils was 16.1 ± 3.5 items kg^{-1}	+++	I
(Yang, Q. et al., 2019)	Agricultural activites (Mulching film)			Film	SegNet model built on three-band (89.62%)and six-band (90.6%) data obtains the optimal average accuracy	++	II
(Piehl et al., 2018)	Atmospheric input (Wind)	MaPs 81 pieces, (PE) with 67.90% (55 particles), (PS; 13.58%,	MPs: Polyethylene (62.50%, 10 particles), PP (25.00%, 4 particles), and PS	MaPs: Film (65.43%) , fragment (25.93%) MPs: Fragments	MPs ranged from 0 to 1.25 MPPs per kilogram DW mean abundance of	+++	I

		11 particles) and (PP; 9.88%, 8 particles), (PVC; 4.94%, 4 particles), (PET; 2.47%, 2 particles), and (PMMA; 1.24%, 1 particle	(12.50%, 2 particles)	(43.75%) and flms (43.75%)	0.34±0.36 per kilogram		
(Zhang, G.S. et al., 2018)	Agricultural activites (Soil amendments and irrigation with wastewater)			Fibers (92%), fragments (4.0%) and films (3.7%)	MPs 7100 to 42,960 particles kg^{-1}(mean 18,760 particles kg^{-1})	+++	I
(Liu, M. et al., 2018)	Agricultural activites (Mulching film and compost by sewage sludge)	MEPs 6.75±1.51 items kg^{-1} (shallow soil) and 3.25±1.04 items kg^{-1}(deep soil)	(PP) (50.51%), (PE) (43.43%), and (PES) (6.06%)	Fibers (53.33%), fragment (37.58%), film (6.67%) and pellet (2.12%) (shallow soil). Fibers (37.62%), films (33.76%), fragments (28.30%) and pellets (0.32%) (deep soil)	78.00±12.91 items kg^{-1} (shallow soil) and 62.50±12.97 items kg^{-1} (deep soil)	+++	I
(Blanco et al., 2018)	Agricultural activities	Covering films was 627 kg ha^{-1}, from the anti-hail nets was 159 kg ha^{-1}, from nets for crop protection was				++	II

		192 kg ha^{-1}, from shading nets was 131 kg ha^{-1}, from irrigation pipes was 104 kg ha^{-1} (Maps and the GIS database)					
(He, H. et al., 2018)	Agricultural activites (Mulching film)			Films	Ranged from 121.85 to 352.38 kg ha^{-1} across the six fields	++	II
(Zhang, S. et al., 2017)	Agricultural activites (Mulching film)		(PE) and (PP)		Agricultural field 0-10 0.008 ± 0.025 (g kg−1), 10-30 0.368 ± 0.740 (g kg−1) Fruit field 0-10 0.540 ± 0.603 (g kg−1), 10-30 0.460 ± 0.735 (g kg−1), Green house field 0-10 0.130 ± 0.307 (g kg−1), 10-30 0.024 ± 0.051 (g kg−1). A calculation based on image J software analysis	++	II
(Zhang, D. et al., 2016)	Agricultural activites (Mulching film)			Film	Ranged from 0.2 to 82.2 kg/hm2 , with an average value of 26.8 kg/hm2	++	II
(Xu, G. et al., 2006)		2400–8200 g ha^{-1}	LDPE	Film		++	II

*Substantiated (+++); partially substantiated (++); unsubstantiated (+)

**I Strong; II moderate; III low

According to the table 3, the principal sources reported are:

Agricultural activities

The use of plastics in agriculture activities provides advantages such as quality, cost, durability, and functionality (soil and crop improvement), but usually, after their use, there is no recycling or lift strategy in consequence, are going to be breakdown and degraded on environmental conditions (Serna-Abascal et al. 2022). The principal plastics for this purpose are the irrigation tubes (Isari et al. 2021), greenhouse covers and film protection, nets (El-Malek et al. 2020), plastic gauze (Mo et al. 2021), coated fertilizers, and the mulching film appears as the most predominate agricultural soil contaminant (Boughattas et al. 2021).

Irrigated with treated wastewater (TWW) and Sewage sludge (biosolids)

The irrigation with treated wastewater (TWW) and the application of sewage sludge as fertilizers are reported as an of the principal sources of the entry of MPs into the soils. A large load of fibers (97-12.5%), fragments(49-4%), film(50-1.6%), and flakes (85.9-18.5%) are found in soils. The water treatment removed plastic particles the micro and nano plastics don’t eliminate and remain in compost products as soil amendments (Kumar et al., 2020).

Atmospheric input

Micro and nano plastic particles were transported between different environments through different media, and in recent years research has focused on the study of atmospheric transport, airborne microplastics can be laydown on agricultural soil by air transport, which transfers the lowest plastic over long distances (Enyoh et al. 2019). These particles have been identified in the atmosphere of urban, suburban, roads, and even remote areas suggesting their potential capacity to transport a large distance (Abbasi et al. 2022)

The problem of plastic pollution is not only for the plastic particles, the formulation of those also contains retardants and additives with phthalate esters considered carcinogenic and mutagenic (Zeng et al. 2020). These compounds are still in a higher proportion of vegetables grown in a greenhouse than in agricultural soil (Chen et al. 2017; El-Malek et al. 2020).

5.5. Conclusion

This systematic literature review with bibliometric indicators show progress in the research, the collaboration between researchers and countries, and the identification of diverse sources of contamination by plastics in agricultural soils. Results demonstrate that their contribution is still emerging in quantity and collaboration among the different scientific actors worldwide; nevertheless, there has been an increase in the number of publications due to the global concern to conserve the environment in line with the sustainable development goals. One point of a gap is the absence of methodology for the identification and quantification of plastic particles under field conditions, as well as their interactions with heavy metals, phthalate esters, and the organic matter contained in the soil. It is necessary to promote this research globally to understand and curb the pollution of different environments and the effects on human health.

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5.8. Conflicts of Interest

The authors declare no conflict of interest.

6. OBTENCIÓN DE FIBRAS DE *Agave Salmiana* Y PRUEBA DE DEGRADABILIDAD

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6.1. Resumen

Se obtuvieron fibras provenientes de *Agave Salmiana* del estado de Tlaxcala, estas se trataron con álcali y se secaron en un deshidratador solar; posteriormente se hilaron para obtener hilos y un tejido textil tipo tramado. Estos tres productos se impregnaron con cera de abeja mediante una bolsa de vacío; para compararlos con sus homólogos sintéticos, se midieron los diámetros y la pérdida de peso de los materiales, el mayor diámetro fueron las fibras con cera (0.1997 mm) y los hilos plásticos (1.2596 mm). La mayor pérdida de peso en todos los especímenes se presentó en las fibras, hilo y malla impregnados de cera en un rango de 12-38% en un período de 30 días, contando con diferencias significativas con los productos sintéticos. Estos hilos y malla de fibras naturales se presentan como una propuesta para disminuir el excesivo uso de plásticos sintéticos en la agricultura, sin embargo, es necesario la caracterización mecánica para que se pueda considerar una alternativa funcional.

6.2. Introducción

En la actualidad se destina el 3.2 % de los plásticos totales aproximadamente 1.57 Mt para su uso en la agricultura, la mayoría son LDPE (Polietileno de baja densidad), LLDPE (Polietileno de baja densidad lineal), PVC y en menor cantidad ABS (Acrilonitrilo butadieno estireno), SAN (Estireno Acrilo-Nitrilo), así como otros termoplásticos (Plastics Europe 2021) . El uso de plásticos sintéticos en la agricultura da ventajas en términos de calidad, durabilidad, funcionalidad y costos necesarios para los niveles requeridos para la producción actual de alimentos (Lin et al. 2009; Huang et al., 2020). Pero la mayoría de las veces después de su periodo de uso, estos plásticos se dejan fracturar y degradar en los entornos en los que se utilizan, generando depositos en cuerpos de agua y suelo sin ningun tratamiento (Serna-Abascal et al*.* 2022).

Por ello, se han desarrollado diversos materiales que prometen un uso seguro y menos agresivo durante toda la cadena de suministro, desde la protección de semillas, granos, el cultivo hasta el transporte de alimentos (Choudhary et al. 2017), estos se han centrado en la protección por medio de películas de quitosano, bioestimulantes, bioimpresión de semillas y cuidados en la producción de hojas, elongación de brotes, etc.; así como el plástico acolchado y los fertilizantes de lenta liberación (Dolmaa et al*.* 2018; Hussain et al*.* 2019).

Una alternativa para la sustitución de estos plásticos sintéticos, es el uso de fibras naturales obtenidas de plantas, animales, y minerales (Ticolau et al. 2013). La composición química de estas fibras en general es celulosa (45-55%), hemicelulosa (25-35%), lignina (20-30%) estos representan el 90% de la masa seca (Ogita et al. 2016), el 10% restante son pectina, cera y sustancias solubles en agua (Li et al. 2007).

Las fibras de *agave* como el *henequén* y *sisal*, se consideran una alternativa por su durabilidad y su dureza, sin embargo, esas propiedades otorgan poca flexibilidad y su uso se ha centrado como relleno de materiales (Reyes-Samilpa et al*.* 2022); en este trabajo se obtuvieron fibras de *Agave Salmiana*, las cuales se trataron como una sola fibra, como un haz de fibras en forma de hilo y como un tramado tejido en forma de malla para probar su degradabilidad en suelo por pérdida de peso y proponer una alternativa a los plásticos sintéticos utilizados en agricultura.

6.3. Materiales y Métodos

Este trabajo se realizó en el laboratorio de Materiales Biológicos y en el secador solar del área de energías alternativas en la Universidad Autónoma Chapingo, Texcoco, Estado de México.

Obtención de fibras

Se recolectaron 80 pencas de 5 años edad de *Agave Salmiana* del ejido denominado *"San Antonio Calpulalpan*", en el municipio de Calpulalpan Estado de Tlaxcala.

A las 80 pencas se les retiraron las espinas, así como el excedente de la punta, posteriormente se dividieron en tres partes, conservando la sección inicial (sección 1) Figura 6.1. Después la sección 1 se dividió en tres partes en dirección a las fibras (Figure 6.2) para evitar la parte cóncava y así facilitar el desfibrado y el manejo (Perez del Río *et al.* 2013).

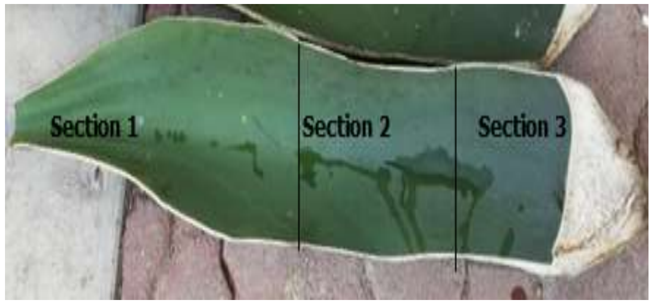

Figure 6.1. Secciones de penca

Figure 6.2. División en tres partes

Con el uso de modelo de utilidad "AGAVE SHREDDER BLADE" se raspó y se obtuvieron los haces de fibra, esta cuchilla (material y dimensiones) contiene un filo necesario para que la porción de la penca pueda cortar la parte exterior de esta sin lastimar o cortar las fibras (Figura 6.3). A los haces de fibras que se obtuvieron, se les dio un tratamiento alcalino con NaOH 5% en un recipiente de 20 L por media hora, estas fibras se enjuagaron por triplicado con agua corriente por 15 minutos hasta contar con un pH de 7 (Kim & Cho 2022) (Figure 6.4). Finalmente, estas fibras se deshidrataron por 5 horas en un secador solar (características , capacidad y de acción) ubicado en la Universidad Autónoma

Chapingo (Figure 6.5), se seleccionó este tipo de secado para evitar el uso en un horno convencional o la exposición de radiación directa a las fibras.

Figure 6.3. Modelo de utilidad “AGAVE SHREDDER BLADE”

Figure 6.4. Fibras tratadas con NaOH

Figure 6.5. Fibras en secador solar

Pruebas físicas

Se evaluaron el diámetro promedio para las fibras y para los hilos. La determinación del diámetro de las fibras se realizó seleccionándose al azar 60 filamentos realizando tres mediciones en la parte media de estas, se utilizó un micrómetro de 0" - 2.5cm /0.0001 de la marca Premium Precision Machinist Tool. Para la medición del diámetro de los hilos se repitió el procedimiento anterior utilizando 30 muestras de cada tipo de hilo.

Hilado y Tejido de fibras

Las fibras finales se *peinaron* y *varearon* para eliminar los restos vegetales que pudieron quedar añadidos a estas, después se trasladaron a la localidad el Decá en Hidalgo con la comunidad "Wäda" (Figure 6.6) y con la ayuda del huso y la rueca se formaron hilos (Figure 6.7), con un telar de cintura el tramado tipo textil, que se asemejan a una malla sombra plástica (Figure 6.8)

Figure 6.6. Comunidad Wäda, el Decá Hidalgo

Figure 6.7. Hilado de fibras

Figure 6.8. Tejido tipo malla

Impregnación de materiales

Las fibras, hilo y malla se impregnaron con un material de origen natural para brindar resistencia a la intemperismo que se presenta por la exposición a la luz/radiación UV, la temperatura y el oxígeno, que provocan deterioro del aspecto y propiedades mecánicas, físicas y químicas (Zhang *et al.* 2022) al que están expuestos estos hilos y mallas sintéticas; para este caso de estudio se realizó con cera de abeja al ser un material de origen natural y se ha utilizado como agente impermeabilizante para la madera y el cuero y para el refuerzo de hilos

(FAO 2005) .Esta cera se colocó en baño maría y cuando se encontraba en estado líquido con la ayuda de una brocha se barnizaron las fibras (Figure 6.9), el tramado (Figure 6.10) y el hilo, posteriormente con la finalidad de optimizar la impregnación de la cera y buscando que se cubra la mayor área superficial del material se utiliza una bomba de vacío, para ello el material debe colocarse en una bolsa de vacío para que la impregnación se diera de manera homogénea (Wang et al. 2022).

Figure 6.9. Impregnación de fibras

Figure 6.10. Impregnación de tejido

Degradación por pérdida de peso

Caracterización de sustrato para la degradación

Se simuló un suelo con la siguiente composición 23% turba, 16% lombricomposta, 15% peat moss y 46% de tierra negra (base peso seco), esta mezcla permite contar con una fuente de carbono durante el tiempo de incubación, lo cual es necesario para las pruebas de biodegradación (Uribe et al. 2011). Se utilizó un potenciómetro PH140 Conductronic para obtener el valor de pH, el cual fue de 6.5 y con un Conductímetro KGD003 se midió una conductividad de 0.89 dSm^{-1}.

Preparación de muestras

Se acondicionó un refrigerador que simulara una incubadora el cual se mantuvo a una temperatura de 30°C ± 5°C y una humedad relativa de 30% ± 10% medidos a través del Data Logger HOBO MX1101. Con la ayuda de una malla metálica (para conservar el material que no se ha degradado), se colocaron entre dos pedazos de esta por triplicado, muestras de fibra con cera y sin cera, hilo plástico hilo de fibra con cera y sin cera; así como malla plástica negra, malla con cera y finalmente malla sin cera (Figura 6.11).

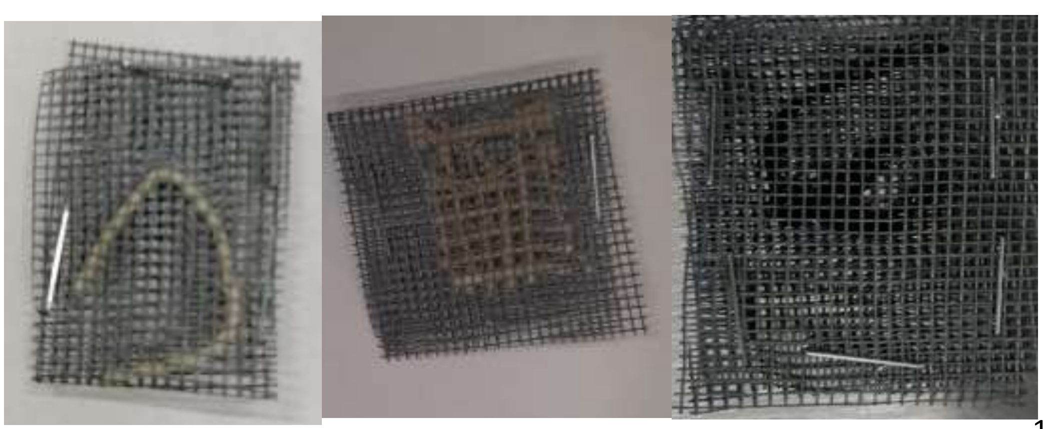

Figure 6.11. Muestras de material para enterrar en sustrato

Método de pérdida de peso

Para determinar el porcentaje en el que las fibras, hilos y malla se biodegradaron, se optó por determinarse por medio de pérdida de peso (Ecuación 1). Con cada una de las muestras totalmente secas se pesaron en una Balanza analítica ADAM-Nimbus®: NBL 124 (wo), posteriormente se colocaron a una distancia de 2 cm del fondo y se cubrieron con el sustrato previamente preparado, la humedad durante todo el experimento se mantuvo entre 35 y 40% agregando 15 ml de agua cada tercer día (Díaz Herrera *et al.* 2022) . Cada tercer día se retiraron del sustrato, se limpiaron con agua y se secaron en un horno RIOSSA H-33 (Riossa, Monterrey, México) a 90 °C hasta peso constante (wf), esto se realizó por 30 días y se obtuvo el porcentaje de biodegradabilidad (Antonio et al. 2020)

$$\%wl = \frac{wo - wf}{wo} * 100$$

Donde $\%wl$ es el porcentaje de pérdida de peso, wo es el peso inicial y wf es el peso final.

Diseño de experimento

Se realizó un diseño experimental completamente al azar con tres repeticiones, se aplicaron dos factores para las fibras: FC (Fibras con cera) y FS (Fibras sin cera); para la malla e hilo tres factores: MC (Malla con cera), MS (Malla sin cera) y MP (Malla plástica); HC (Hilo con cera), HS (Hilo sin cera) y HP (Hilo plástico).

Análisis estadístico

Para el análisis estadístico de los datos, se realizó un ANOVA de un solo factor con dos niveles para las fibras y de tres niveles para el hilo y la malla para identificar el efecto de los factores sobre la pérdida de peso. Se realizó una prueba de comparación de medias (Tukey, 0.05).

6.4. Resultados y Discusión

Se obtuvieron fibras de *Agave Salmiana* de características físicas adecuadas para ser utilizadas como materia prima en la formación de hilos y tejido de tipo tramado malla sombra.

Diámetro promedio de Fibra

De acuerdo con la tabla 6.1, el diámetro promedio de las fibras con o sin cera son significativamente diferentes, aportando la cera un recubrimiento que las engrosa, lo cual supondría una mejor protección. Se ha reportado diámetros de 0.137 mm (Sanjuan-Raygoza et al. 2009), 0.253 mm y 0.333 mm (Castillo Quiroz *et al.* 2013), el valor que se obtuvo se encuentra dentro del rango, es necesario decir que el valor del diámetro de la fibra depende de diversos factores como lo son el lugar de cosecha, el tipo de agave, la parte de la penca de la que se obtuvo la fibra por esta razón se cuentan con distintos valores (Ramesh 2018).

Table 6.1. Diámetro promedio de las fibras

Tratamiento	Diámetro promedio (mm)	Comparación
Fibra sin cera (FC)	0.1997	A
Fibra con cera (FS)	0.16339	B

*Las letras diferentes significan una diferencia significativa (Tukey 0.05)

En lo referente al diámetro medio de los hilos, se obtuvieron los siguientes valores (Tabla 6.2) donde se observa que si existe una diferencia significativa entre el hilo sin cera y los hilos con cera y plástico; esto se explica debido a que el hilado es completamente manual y el plástico es con maquinaría, sin embargo, así como en la fibra la aplicación de la cera engrosa y aumenta el diámetro.

Table 6.2. Diámetro promedio de los hilos

Tratamiento	Diámetro medio (mm)	Comparación
Hilo sin cera (HS)	0.7537	A
Hilo con cera (HC)	0.8071	B
Hilo plástico (HP)	1.2596	B

*Las letras diferentes significan una diferencia significativa (Tukey 0.05)

Pérdida de Peso

Fibras

Se analizaron por separado las fibras, los hilos y las mallas; encontrando que entre las fibras no existe una diferencia significativa en cuanto a la aplicación de cera en la biodegradabilidad, aunque el mayor porcentaje se reporta en las fibras que contienen cera (Tabla 6.3).

Table 6.3 Pérdida de peso promedio de las fibras

Tratamiento	Pérdida de peso%	Comparación
Fibra sin cera (FS)	8.03	A
Fibra con cera (FC)	12.03	A

*Las letras diferentes significan una diferencia significativa (Tukey 0.05)

En la Tabla 4 se observa el ANOVA donde se corrobora que no hay diferencias significativas en cuanto a la pérdida de peso

Table 6.4 ANOVA de un solo factor para las fibras en la pérdida de peso

FV	GL	SC	CM	Fc	Valor de p
Tratamiento	1	24.01	24.01	0.47	0.53
Error	4	203.53	50.88		

Total	5	227.54

FV= variation factor; GL = degrees of freedom; SC = sum of squares; CM = mean square; Fc = correction factor ;** = Highly significant (p<0.05).

Hilo

La pérdida de peso que se obtuvo en los hilos resultó ser significativa entre los diferentes tratamientos, se observa que la que presentó mayor pérdida de peso es aquel hilo que se encontraba recubierto de cera, seguido de aquel que no estaba recubierto y por último el hilo plástico (Tabla 6.5). Estos resultados se explican dado que la cera al ser un material orgánico, rico en Carbono se muestra como un ambiente propicio para el crecimiento de microorganismos, por tanto, otorga mayor degradación siendo esto un requisito deseable siempre en este tipo de experimento (Uribe et al*.* 2011) (Tabla 6.6).

Table 6.5. Pérdida de peso promedio de los hilos

Tratamiento	Pérdida de peso %	Comparación
Hilo con cera (HC)	23.667	A
Hilo plástico (HP)	4.793	B
Hilo sin cera (HS)	14.52	C

*Las letras diferentes significan una diferencia significativa (Tukey 0.05)

Table 6.6. ANOVA de un solo factor para los hilos en la pérdida de peso

FV	GL	SC	CM	Fc	Valor de p
Tratamiento	2	534.56	267.278	86.22	0
Error	6	18.6	3.1		
Total	8	553.16			

FV= variation factor; GL = degrees of freedom; SC = sum of squares; CM = mean square; Fc = correction factor ;** = Highly significant (p<0.05).

Malla

La malla sombra reporta diferencias significativas entre la malla plástica, la malla sin cera y la malla con cera siendo el valor numérico casi en un orden de 10 veces mayor la pérdida de peso de la malla con cera (Tabla 6.7). En esta parte no existen diferencias significativas entre la pérdida de peso de la malla sin y con cera, pero concuerda con las fibras e hilos donde las mayores pérdidas de peso son en aquellas que están recubiertas con la cera de abeja (Tabla 6.8). Se han reportado algunos materiales en forma de lámina, que podrían utilizarse para labores agrícolas (Mejía et al. 2007) donde también se confirma que la degradación aumenta con el intemperismo al que son expuestas por las labores propias.

Table 6.7. Pérdida de peso promedio de las mallas

Tratamiento	**Pérdida de peso**	**Comparación**
Malla con cera (MC)	37.13	A
Malla plástica (MP)	3.248	A B
Malla sin cera(MS)	21.84	B

*Las letras diferentes significan una diferencia significativa (Tukey 0.05)

Table 6.8. ANOVA de un solo factor para los hilos en la pérdida de peso

FV	GL	SC	CM	Fc	Valor de p
Tratamiento	2	1727.4	863.72	12.79	0.007
Error	6	407.2	67.86		
Total	8	2134.6			

FV= variation factor; GL = degrees of freedom; SC = sum of squares; CM = mean square; Fc = correction factor ;** = Highly significant ($p<0.05$).

En el presente, existe la Norma “NOM-161-SEMARNAT-2011”, donde en su **Listado de Residuos de Manejo Especial Sujetos a Plan de Manejo** a los plásticos usados en la agricultura le competen el ***numeral II.*** *Los residuos agroplásticos generados por las actividades intensivas agrícolas, silvícolas y forestales; y el* ***numeral III****. Los residuos orgánicos de las actividades intensivas agrícolas, avícolas, ganaderas y pesqueras.* Esta Norma regula pero aún existen vacíos legales que no permiten establecer líneas claras de acción así como sanciones para lograr una adecuada disposición y eliminación de este tipo de residuos; lo que se plantea es aprovechar el poder calorífico de estos plásticos para producir energía, no obstante, si esto no se realiza de manera adecuada puede generar problemas más graves de contaminación atmosférica (SAGARPA 2015).

6.5. Conclusión

La implementación de alternativas a los plásticos sintéticos usados en la agricultura es un tema de relevancia e impacto mundial que debe atenderse urgentemente ya que la generación de alimento no es algo que disminuya, por el contrario, aumentará, por esto se proponen alternativas como las que se presentan en este trabajo. El uso de fibras naturales que puedan ser moldeadas en hilos como alternativa a la rafia agrícola y tejido en forma de trama para la sustitución de la malla sombra sintética, es necesario que sean parte de la solución contando con niveles de biodegradabilidad en ambientes donde se dará su disposición final como lo es el suelo. En esta etapa la propuesta es una opción segura para el ambiente, sin embargo, es necesario la caracterización de los propiedades mecánicas para que se convierta en una solución rentable, adecuada y útil para la sustitución de los plásticos sintéticos que actualmente se utilizan.

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6.7. Conflicto de interés

Los autores declaran que no existe conflicto de interés

7. APPENDIX: “UTILITY MODEL OF *AGAVE* SHREDDER BLADE”

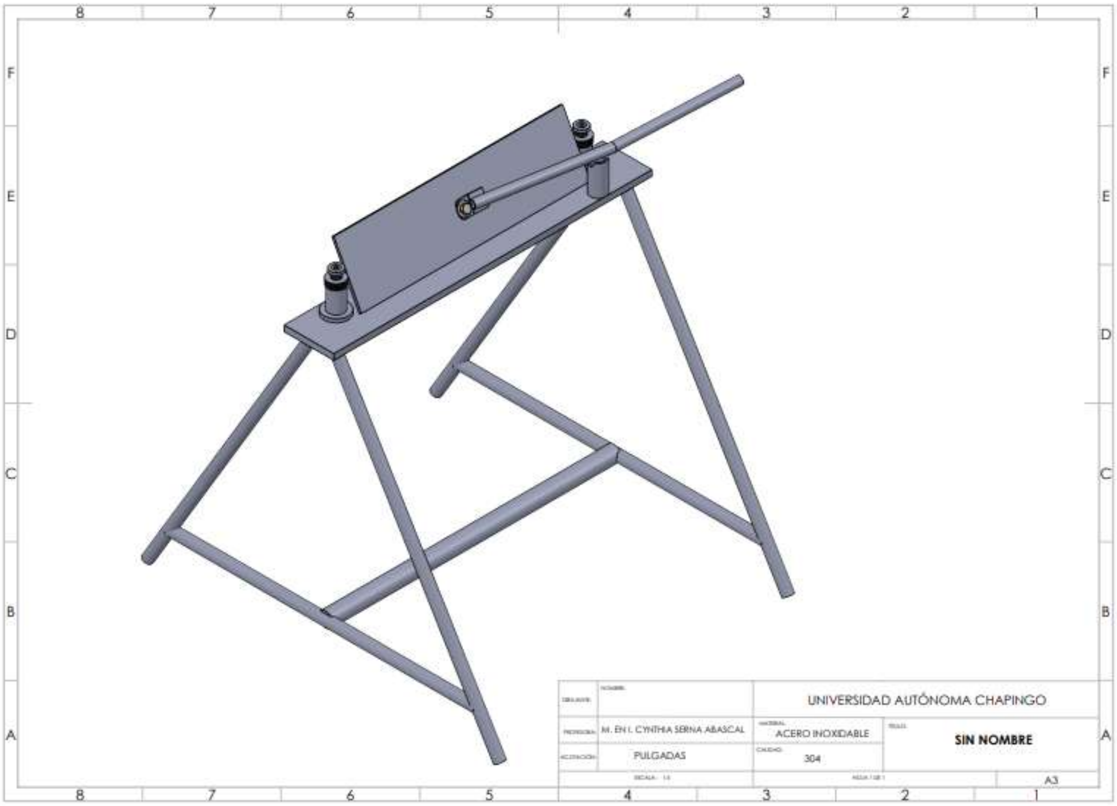

Figure 7.1. Technical drawings of Agave shredder blade

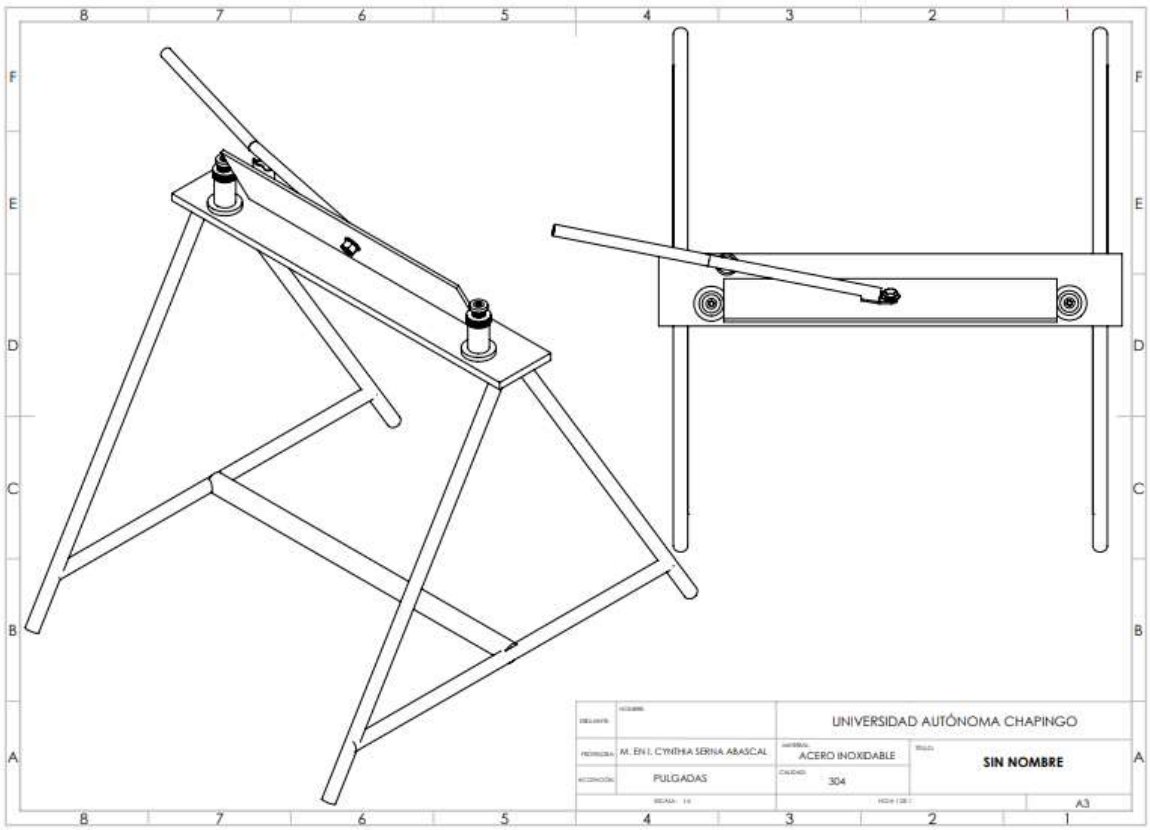

Figure 7.2. Technical drawings of Agave shredder blade