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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 raw 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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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.

MATERIALS AND METHODS

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 0of 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 01)

Table 01: 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 02). 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 02). Identification and removal of 142 duplicate references left only 1,262 working documents (Figure 01). The latest search was updated in November 2020.

Table 02: Set of searches with general and specific keywords

General and specific keywords	Number of scientific articles
(TITLE-ABS-KEY (biomaterials) AND TITLE-ABS-KEY (agriculture OR farmland OR agricultural OR "Agricultural Soil" OR "Agricultural Land"))	374
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 ("Eco Composites") AND TITLE-ABS-KEY (agriculture OR farmland OR agricultural OR "Agricultural Soil" OR "Agricultural Land"))	55
Total of articles	1404

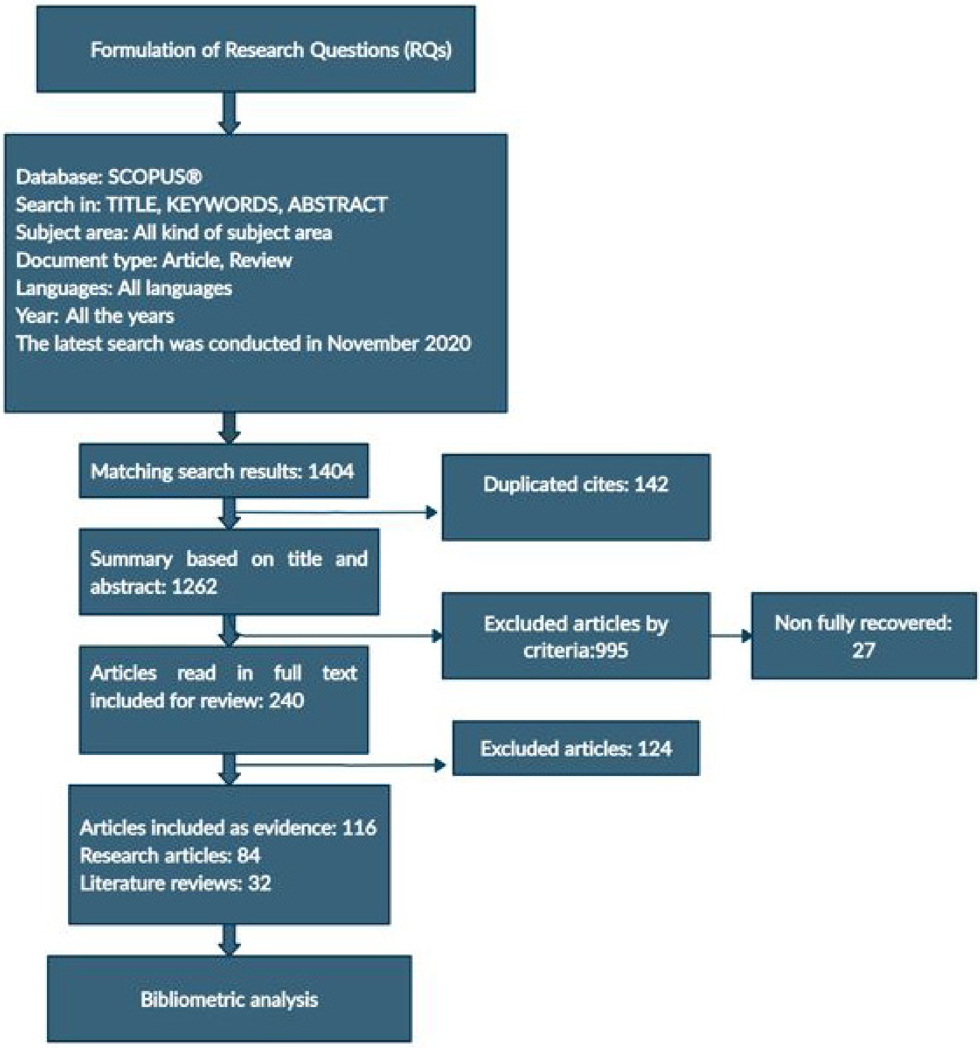

Figure 01: Selection procedure of scientific articles. adjusted from Márcio (2016) methodology

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.

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).

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

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 c_{ij} 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.

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 03 summarizes the definition adopted by each concept based on the scientific information consulted.

Descriptive bibliometric analysis

The information about the 116 articles published between 1992 and 2021, extracted by the database Scopus® is summarized in Table 04.

Publications

A growing trend in scientific production is observed from 2005 with slight decreases in 2010, 2012, 2015, and 2017 (Figure 02). 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).

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).

Table 03: 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 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 *et al.,* 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.		(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);

Primary concept	Secondary concept	References
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.	(Verma and Fortunati, 2019)
	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.	
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 0polymers 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.		(Niaounakis, 2013a); (Verma and Fortunati, 2019)

Table 04: 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

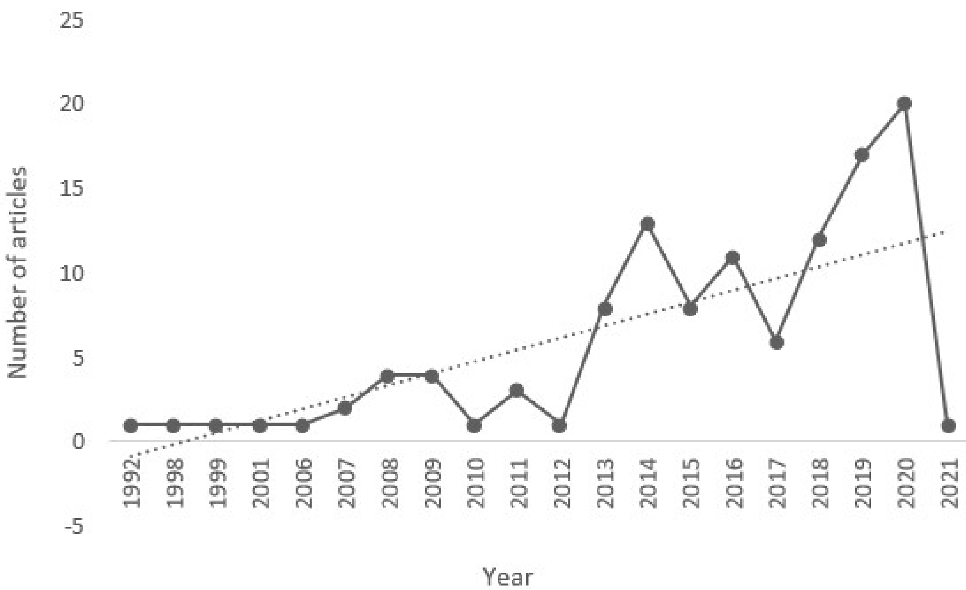

Figure 02: Timeline of related scientific publications in alternative materials used in agriculture

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 05, 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).

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 03). 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.

Table 05: 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)*

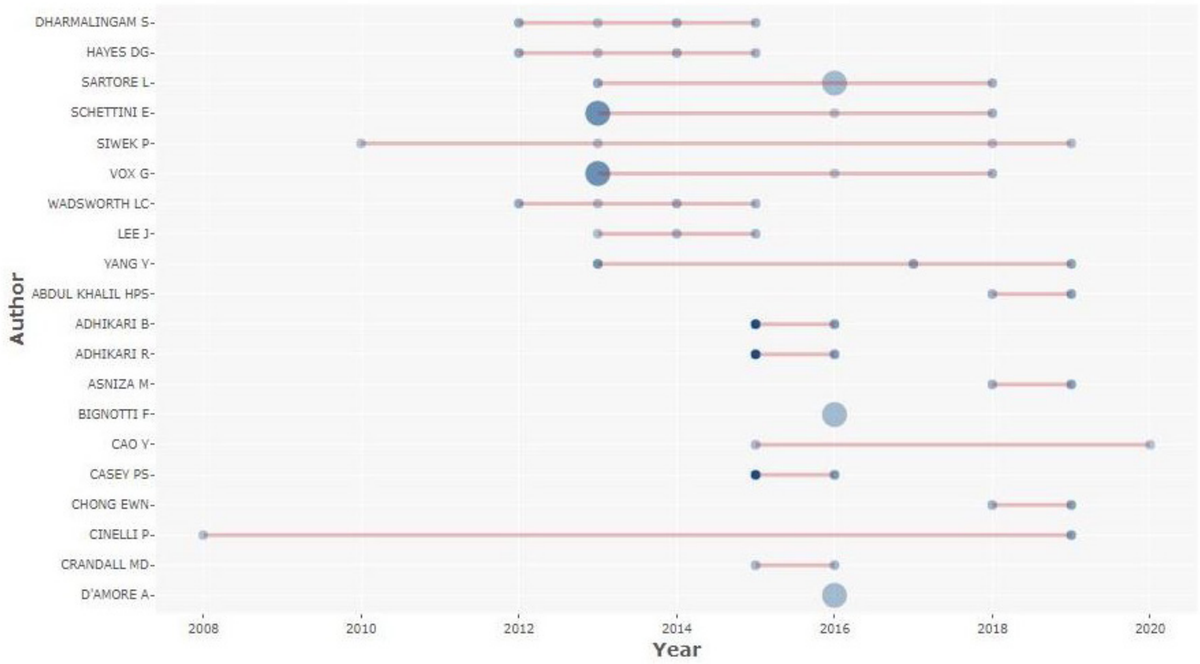

Figure 03: **Top authors' production over time in the developing of alternative materials (R-tool for Bibliometrix: Biblioshiny, 2020)**

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 06). 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).

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 07). 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 04).

Table 06: 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

Table 07: 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 04: **Bibliometric network of keywords in development of alternative materials used in agriculture (VOS Viewer, 2020)**

This analysis is consistent with the information in Table 08, 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 08: **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)

CONCLUSIONS

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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Conflicts of Interest

The authors declare no conflict of interest.

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