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 1990).
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 0 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 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                         |
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
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aims to know whether there are connections or not, among authors, countries, identify emergent and influential topics, and point out gaps 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 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 \( c_{ij} \) 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: | Bioplastic. Should satisfy one or two of the criteria:                                          | (Kyrikou and Briassoulis, 2007); (Abdul Khalil et al., 2012); (Rudin and Phillip, 2013); |
| • Matrix (polymer or resin [biodegradable or non-biodegradable]) | • Biotechnological origin: partially or totally bio-based, from a renewable source             | (Niaounakis, 2013a); (Haraguchi, 2014); (Narasimhan et al., 2016); (Sapuan, 2017);            |
| • Reinforcement (usually fibers)                                                                 | • Biodegradable and / or compostable.                                                          | (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 coproducts with high cellulose content. They are also named biobased. Also called "green thermoplastic biocomposites from agricultural fibers" |                                                                                                 |                                                                                                 |
| 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. |                                                                                                 |                                                                                                 |
| 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. |                                                                                                 |                                                                                                 |

(Vaca-Garcia, 2008); (Dahy, 2017) (Raghavendra et al., 2015) (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. CompostTable 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*** | Affiliation                              |
|-------------------|---------|------|------|--------|------------------------------------------|
| 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)
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                     |
This analysis is consistent with the information in Table 08, as it shows that developments mostly focus on mulching materials, hydrogels, slow release 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); (Saalah 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); (Dabbagh 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) |
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.
REFERENCES

Abdul Khalil, H. P. S., Bhat, A. H., and Ireana Yusra, A. F. (2012) Green composites from sustainable cellulose nanofibrils: A review. *Carbohydrate Polymers*, 87(2), 963–979. https://doi.org/10.1016/j.carbpol.2011.08.078

Abdul Khalil, H. P. S., Chong, E. W. N., Owolabi, F. A. T., Asniza, M., Tye, Y. Y., Rizal, S., Nurul, F.M. R., Mohamad, H.M. K., Nurmiati Z., and Paridah, M. T. (2018a) Enhancement of basic properties of polysaccharide-based composites with organic and inorganic fillers: A review. *Journal of Applied Polymer Science*, 47251. https://doi.org/10.1002/app.47251

Abdul Khalil, H. P. S., Chong, E. W. N., Owolabi, F. A. T., Asniza, M., Tye, Y. Y., Tajarudin, M.T. Paridah, and Rizal, S. (2018b) Microbial-induced CaCO3 filled seaweed-based film for green plasticulture application. *Journal of Cleaner Production*, 199, 150–163. https://doi.org/10.1016/j.jclepro.2018.07.111

Adeleye, A. T., Odoh, C. K., Enudi, O. C., Banjoko, O. O., Osigbeminiyi, O. O., Toluwalope, O. E., and Louis, H. (2020) Sustainable synthesis and applications of polyhydroxyalkanoates (PHAs) from biomass. *Process Biochemistry*. https://doi.org/10.1016/j.procbio.2020.05.032

Adhikari, R., Bristow, K. L., Casey, P. S., Freischmidt, G., Hornbuckle, J. W., and Adhikari, B. (2016) Preformed and sprayable polymeric mulch film to improve agricultural water use efficiency. *Agricultural Water Management*, 169, 1–13. https://doi.org/10.1016/j.agwat.2016.02.006

Alves, V. D., Torres, C. A. V. and Freitas, F. (2016) ‘Bacterial polymers as materials for the development of micro/nanoparticles’, *International Journal of Polymeric Materials and Polymeric Biomaterials*, 65(5), pp. 211–224. https://doi.org/10.1080/00914037.2015.1103239

Ammala, A., Bateman, S., Dean, K., Petinakis, E., Sangwan, P., Wong, S., Yuan Q., Yua L., Patrick C., and Leong, K. H. (2011) An overview of degradable and biodegradable polyolefins. *Progress in Polymer Science*, 36(8), 1015–1049. doi:10.1016/j.progpolymsci.2010.12.002

Aria, M., and Cuccurullo, C. (2017) ‘bibliometrix: An R-tool for comprehensive science mapping analysis’, *Journal of Informetrics*. Elsevier Ltd, 11(4), pp. 959–975. https://doi.org/10.1016/j.joi.2017.08.007.

Baraibar-Diez, E., Luna, M., Odriozola, M. D., and Llorente, I. (2020) Mapping Social Impact: A Bibliometric Analysis. *Sustainability*, 12(22), 9389. https://doi.org/10.3390/su12229389

Bastioli, C. (2001) ‘Global status of the production of biobased packaging materials’, *Starch/Staerke*, 53(8), pp. 351–355. https://doi.org/10.1002/1521-379X(200108)53:8<351::AID-STAR351>3.0.CO;2-R.

Bettas Ardisson, G., Tosin, M., Barbale, M., and Degli-Innocenti, F. (2014) Biodegradation of plastics in soil and effects on nitrification activity. A laboratory approach. *Frontiers in Microbiology*, 5. https://doi.org/10.3389/fmicb.2014.00710

Briassoulis, D., Babou, E., Hiskakis, M., Scarascia, G., Picuno, P., Guarde, D., and Dejean, C. (2013) Review, mapping and analysis of the agricultural plastic waste generation and consolidation in Europe. *Waste Management & Research*, 31(12), 1262–1278. https://doi.org/10.1177/0734242x13507968
Briassoulis, D. and Giannoulis, A. (2018) ‘Evaluation of the functionality of bio-based plastic mulching films’, *Polymer Testing*. Elsevier, 67(February), pp. 99–109. https://doi.org/10.1016/j.polymertesting.2018.02.019

Briones, R., Torres, L., Saravia, Y., Serrano, L., and Labidi, J. (2015) Liquefied agricultural residues for film elaboration. *Industrial Crops and Products*, 78, 19–28. https://doi.org/10.1016/j.indcrop.2015.10.021

Bucki, P., Siwek, P., Domagała-Świątkiewicz, I., and Puchalski, M. (2018) Effect of Agri-Environmental Conditions on the Degradation of Spunbonded Polypropylene Nonwoven with a Photoactivator in Mulched Organically Managed Zucchini. *Fibres and Textiles in Eastern Europe*, 26(2), pp. 55–60. https://doi.org/10.5604/01.3001.0011.5739

Calcagnile, P., Sibilliano, T., Giannini, C., Sannino, A., and Demitri, C. (2019) Biodegradable poly(lactic acid)/cellulose-based superabsorbent hydrogel composite material as water and fertilizer reservoir in agricultural applications. *Journal of Applied Polymer Science*, 47546. https://doi.org/10.1002/app.47546

Cao, Y., Lim, E., Xu, M., Weng, J., and Marelli, B. (2020) Precision Delivery of Multiscale Payloads to Tissue-Specific Targets in Plants. *Advanced Science*, 1903551. https://doi.org/10.1002/advs.201903551

Chamas, A., Moon, H., Zheng, J., Qiu, Y., Tabassum, T., Jang, J. H., Omar M., Scott S., and Suh, S. (2020) Degradation Rates of Plastics in the Environment. *ACS Sustainable Chemistry & Engineering*. https://doi.org/10.1021/acssuschemeng.9b06635

Chandra, R. and Rustgi, R. (1998) ‘Biodegradable polymers’, *Progress in Polymer Science* (Oxford), 23(7), pp. 1273–1335. https://doi.org/10.1016/S0079-6700(97)00039-7

Chiappero, L. R., Bartolomei, S. S., Estenoz, D. A., Moura, E. A. B., and Nicolau, V. V. (2020) Lignin-Based Polyethylene Films with Enhanced Thermal, Opacity and Biodegradability Properties for Agricultural Mulch Applications. *Journal of Polymers and the Environment*, 29(2), 450–459. https://doi.org/10.1007/s10924-020-01886-6

Chiellini, E., Cinelli, P., Magni, S., Miele, S., and Palla, C. (2008) Fluid biomulching based on poly(vinyl alcohol) and fillers from renewable resources. *Journal of Applied Polymer Science*, 108(1), 295–301. https://doi.org/10.1002/app.27571

Chowdhury, M. A. (2014) ‘The controlled release of bioactive compounds from lignin and lignin-based biopolymer matrices’, *International Journal of Biological Macromolecules*. Elsevier B.V., 65, pp. 136–147. https://doi.org/10.1016/j.ijbiomac.2014.01.012

Cinelli, P., Seggiani, M., Mallegni, N., Gigante, V., and Lazzeri, A. (2019) Processability and Degradability of PHA-Based Composites in Terrestrial Environments. *International Journal of Molecular Sciences*, 20(2), 284. https://doi.org/10.3390/ijms20020284

Cota-Arriola, O., Cortez-Rocha, O., Burgos-Hernández, A., Ezquerra-Brauer, J.M., and Plascencia-Jatomea, M. (2013) Controlled release matrices and micro/nanoparticles of chitosan with antimicrobial potential: development of new strategies for microbial control in agriculture. *Journal of the Science of Food and Agriculture*, 93(7), 1525–1536. https://doi.org/10.1002/jsfa.6060

Clelj, G. (1959) ‘Use of plastic tubes in raising beet seedlings’, *Euphytica*, 8(1), pp. 89–92. https://doi.org/10.1007/BF00022093
Dabbaghi, A. and Rahmani, S. (2018) Synthesis and characterization of biodegradable multicomponent amphiphilic conetworks with tunable swelling through combination of ring-opening polymerization and “click” chemistry method as a controlled release formulation for 2,4-dichlorophenoxyacetic acid. Polymers for Advanced Technologies. https://doi.org/10.1002/pat.4474

Dahy, H. (2017) ‘Biocomposite materials based on annual natural fibres and biopolymers – Design, fabrication and customized applications in architecture’, Construction and Building Materials. Elsevier Ltd, 147, pp. 212–220. https://doi.org/10.1016/j.conbuildmat.2017.04.079

De Corato, U., De Bari, I., Viola, E., and Pugliese, M. (2018) Assessing the main opportunities of integrated biorefining from agro-bioenergy co/by-products and agroindustrial residues into high-value added products associated to some emerging markets: A review. Renewable and Sustainable Energy Reviews, 88, 326–346. https://doi.org/10.1016/j.rser.2018.02.041

De Souza Machado, A. A., Kloas, W., Zarfl, C., Hempel, S., and Rillig, M. C. (2018) Microplastics as an emerging threat to terrestrial ecosystems. Global Change Biology, 24(4), 1405–1416. https://doi.org/10.1111/gcb.14020

Dharmalingam, S., Hayes, D. G., Wadsworth, L. C., Dunlap, R. N., DeBruyn, J. M., Lee, J., and Wszelaki, A. L. (2015) Soil Degradation of Polylactic Acid/Polyhydroxyalkanoate-Based Nonwoven Mulches. Journal of Polymers and the Environment, 23(3), 302–315. https://doi.org/10.1007/s10924-015-0716-9

Díez-Pascual, A. M. (2019) ‘Synthesis and applications of biopolymer composites’, International Journal of Molecular Sciences, 20(9). https://doi.org/10.3390/ijms20092321

Dinh-Audoin, M-T. (2016) Plant-based chemistry: Biobased materials in everyday life. [La chimie du végétal : Du biosourcé au quotidien] Actualite Chimique, (407), pp. 13–16. Available at: https://new.societechimiquedefrance.fr/wp-content/uploads/2019/12/2016-407-mai-p13-dinh-hd.pdf

Elango, B. and Rajendran, Dr. (2012) ‘Authorship trends and collaboration pattern in the marine sciences literature: a scientometric study’, International Journal of Information Dissemination and Technology, (May 2014). Available at: https://www.researchgate.net/publication/232763775_Authorship_Trends_and_Collaboration_Pattern_in_the_Marine_Sciences_Literature_A_Scientometric_Sudy

El-malek, F. A., Khairy, H., Farag, A., and Omar, S. (2020) The sustainability of microbial bioplastics, production and applications. International Journal of Biological Macromolecules. https://doi.org/10.1016/j.ijbiomac.2020.04.07

Feng, S., Wang, J., Zhang, L., Chen, Q., Yue, W., Ke, N., and Xie, H. (2020) Coumarin-Containing Light-Responsive Carboxymethyl Chitosan Micelles as Nanocarriers for Controlled Release of Pesticide. Polymers, 12(10), 2268. https://doi.org/10.3390/polym12102268

Fernández-Pérez, M., Garrido-Herrera, F. J., and González-Pradas, E. (2011) Alginate and lignin-based formulations to control pesticides leaching in a calcareous soil. Journal of Hazardous Materials, 190(1-3), 794–801. https://doi.org/10.1016/j.jhazmat.2011.03.118

George, A., Sanjay, M.R., Srisuk, R., Parameswaranpillai, J., and Siengchin, S.(2020) ‘A comprehensive review on chemical properties and applications of biopolymers and their composites’, International Journal of Biological Macromolecules. Elsevier B.V., 154, pp. 329–338. https://doi.org/10.1016/j.ijbiomac.2020.03.120
Gewert, B., Plassmann, M. M. and Macleod, M. (2015) ‘Pathways for degradation of plastic polymers floating in the marine environment’, Environmental Sciences: Processes and Impacts. Royal Society of Chemistry, 17(9), pp. 1513–1521. https://doi.org/10.1039/c5em00207a

Geyer, R., Jambeck, J. R. and Law, K. L. (2017) ‘Production, use, and fate of all plastics ever made’, Science Advances, 3(7), pp. 25–29. https://doi.org/10.1126/sciadv.1700782

Girgenti, V., Peano, C., Baudino, C., and Tecco, N. (2014) From “farm to fork” strawberry system: Current realities and potential innovative scenarios from life cycle assessment of non-renewable energy use and green house gas emissions. Science of The Total Environment, 473-474, 48–53. https://doi.org/10.1016/j.scitotenv.2013.11.133

Gómez-Martínez, D., Partal, P., Martínez, I., and Gallegos, C. (2009) Rheological behaviour and physical properties of controlled-release gluten-based bioplastics. Bioresource Technology, 100(5), 1828–1832.https://doi.org/10.1016/j.biortech.2008.10.01

Gómez-Martínez, D., Partal, P., Martínez, I., and Gallegos, C. (2013) Gluten-based bioplastics with modified controlled-release and hydrophilic properties. Industrial Crops and Products, 43, 704–710. https://doi.org/10.1016/j.indcrop.2012.08.007

Hablot, E., Dharmalingam, S., Hayes, D. G., Wadsworth, L. C., Blazy, C., and Narayan, R. (2014) Effect of Simulated Weathering on Physicochemical Properties and Inherent Biodegradation of PLA/PHA Nonwoven Mulches. Journal of Polymers and the Environment, 22(4), 417–429. https://doi.org/10.1007/s10924-014-0697-0

Haraguchi, K. (2014) ‘Biocomposites Recent Studies on Biocomposites Fundamental Properties of NC Gels and M-NCs’, Encyclopedia of Polymeric Nanomaterials, pp. 1–8. https://doi.org/10.1007/978-3-642-36199-9

Hayes, D. G., Dharmalingam, S., Wadsworth, L. C., Leonas, K. K., Miles, C., and Inglis, D. A. (2012) Biodegradable Agricultural Mulches Derived from Biopolymers. Degradable Polymers and Materials: Principles and Practice (2nd Edition), 201–223.https://doi.org/10.1021/bk-2012-1114.ch013

Hirsch, J. E. (2005) ‘An index to quantify an individual’s scientific research output’, Proceedings of the National Academy of Sciences of the United States of America, 102(46), pp. 16569–16572. https://doi.org/10.1073/pnas.0507655102

Horejs, C. (2020) ‘Solutions to plastic pollution’, Nature Reviews Materials. Springer US, 5(9), p. 641. https://doi.org/10.1038/s41578-020-00237-0

Horton, A. A., Walton, A., Spurgeon, D. J., Lahive, E., and Svendsen, C. (2017) Microplastics in freshwater and terrestrial environments: Evaluating the current understanding to identify the knowledge gaps and future research priorities. Science of The Total Environment, 586, 127–141. https://doi.org/10.1016/j.scitotenv.2017.01.190

Hsieh J-C, Lin C-W, Lou C-W, Hsing W-H, Hsieh C-T, Kuo C-Y, and Lin J-H. (2017) ‘Geo-textiles for side slope protection: Preparation and characteristics’, Fibres and Textiles in Eastern Europe, 25(1), pp. 102–107. https://doi.org/10.5604/12303666.1227889

Huang, Y., Liu, Q., Jia, W., Yan, C., and Wang, J. (2020) Agricultural plastic mulching as a source of microplastics in the terrestrial environment. Environmental Pollution, 114096. https://doi.org/10.1016/j.envpol.2020.114096
Idumah, C. I. and Hassan, A. (2016) ‘Emerging trends in eco-compliant, synergistic, and hybrid assembling of multifunctional polymeric bionanocomposites’, Reviews in Chemical Engineering, 32(3), pp. 305–361. https://doi.org/10.1515/revce-2015-0046

Ivanov, V., Stabnikov, V., Ahmed, Z., Dobrenko, S., and Saliuk, A. (2014) Production and applications of crude polyhydroxyalkanoate-containing bioplastic from the organic fraction of municipal solid waste. International Journal of Environmental Science and Technology, 12(2), 725–738. https://doi.org/10.1007/s13762-014-0505-3

Jansen, L., M. Henskens, and F. Hiemstra. (2019) “Report on Use of Plastics in Agriculture.” Report Healthy World Cooperation, Wageningen. Available at: https://saiplatform.org/wp-content/uploads/2019/06/190528-report_use-of-plastics-in-agriculture.pdf.

Jiménez-Rosado, M., Pérez-Puyana, V., Cordobés, F., Romero, A., and Guerrero, A. (2018) Development of soy protein-based matrices containing zinc as micronutrient for horticulture. Industrial Crops and Products, 121, 345–351. https://doi.org/10.1016/j.indcrop.2018.05.039

Kaur, S. and Dhillon, G. S. (2014) ‘The versatile biopolymer chitosan: Potential sources, evaluation of extraction methods and applications’, Critical Reviews in Microbiology, 40(2), pp. 155–175. https://doi.org/10.3109/1040841X.2013.770385

Khushbu and Warkar, S. G. (2020) ‘Potential applications and various aspects of polyfunctional macromolecule- carboxymethyl tamarind kernel gum’, European Polymer Journal. Elsevier, 140(July), p. 110042. https://doi.org/10.1016/j.eurpolymj.2020.110042

Khushbu, Warkar, S. G. and Kumar, A. (2019) ‘Synthesis and assessment of carboxymethyl tamarind kernel gum based novel superabsorbent hydrogels for agricultural applications’, Polymer. Elsevier, 182(September), p. 121823. https://doi.org/10.1016/j.polymer.2019.121823

Kijchavengkul, T., Auras, R., Rubino, M., Ngouajio, M., and Fernandez, R. T. (2008) Assessment of aliphatic–aromatic copolyester biodegradable mulch films. Part I: Field study. Chemosphere, 71(5), 942–953. https://doi.org/10.1016/j.chemosphere.2007.10.074

Klein, M. and Poverenov, E. (2020) ‘Natural biopolymer-based hydrogels for use in food and agriculture’, Journal of the Science of Food and Agriculture, 100(6), pp. 2337–2347. https://doi.org/10.1002/jsfa.10274

Kołodziejczyk, M., Oleksy, A., Kulig, B., and Lepiarczyk, A. (2019) Early potato cultivation using synthetic and biodegradable covers. Plant, Soil and Environment, 65(No. 2), 97–103. https://doi.org/10.17221/754/2018-pse

Kong, C., Park, H. and Lee, J. (2014) ‘Study on structural design and analysis of flax natural fiber composite tank manufactured by vacuum assisted resin transfer molding’, Materials Letters. Elsevier, 130, pp. 21–25. https://doi.org/10.1016/j.matlet.2014.05.042

Krauskopf, E. (2018) A bibliometric analysis of the Journal of Infection and Public Health: 2008–2016. Journal of Infection and Public Health, 11(2), 224–229. https://doi.org/10.1016/j.jiph.2017.12.011

Kuo, D.-L., and Wu, T.-M. (2018) Crystallization Behavior and Morphology of Hexadecylamine-Modified Layered Zinc Phenylphosphonate and Poly(Butylene Succinate-co-Adipate) Composites with Controllable Biodegradation Rates. Journal of Polymers and the Environment. https://doi.org/10.1007/s10924-018-1319-z
Kyrikou, I., Briassoulis, D. (2007) Biodegradation of Agricultural Plastic Films: A Critical Review. *Journal of Polymers and the Environment*, 15(2), 125–150. https://doi.org/10.1007/s10924-007-0053-8

Lakitan, B., Erna S., Kartika K., and Yunindyawati, Y. (2019) Use of Scleria Poaeformis as Biomaterial in Etno-Agricultural Practice at Riparian Wetlands in Indonesia.” *Bulgarian Journal of Agricultural Science* 25 (2): 320–25. Available at: https://www.researchgate.net/publication/333043559_Use_of_Scleria_poaeformis_as_biomaterial_in_etno-agricultural_practice_at_riparian_wetlands_in_Indonesia

Li, C., Moore-Kucera, J., Miles, C., Leonas, K., Lee, J., Corbin, A., and Inglis, D. (2014) Degradation of Potentially Biodegradable Plastic Mulch Films at Three Diverse U.S. Locations. *Agroecology and Sustainable Food Systems*, 38(8), 861–889. https://doi.org/10.1080/21683565.2014.884515

Li, Q., Dunn, E. T., Grandmaison, E. W., and Goosen, M. F. A. (1992) Applications and Properties of Chitosan. *Journal of Bioactive and Compatible Polymers*, 7(4), 370–397. https://doi.org/10.1177/088391159200700406

Liu, X., Yang, Y., Gao, B., Li, Y., and Wan, Y. (2017) Environmentally Friendly Slow-Release Urea Fertilizers Based on Waste Frying Oil for Sustained Nutrient Release. *ACS Sustainable Chemistry & Engineering*, 5(7), 6036–6045. https://doi.org/10.1021/acssuschemeng.7b00882

Lu, H., Madbouly, S. A., Schrader, J. A., Srinivasan, G., McCabe, K. G., Grewell, D., Kessler, M.R., Graves, W. R. (2014) Biodegradation Behavior of Poly(lactic acid) (PLA)/Distiller’s Dried Grains with Solubles (DDGS) Composites. *ACS Sustainable Chemistry & Engineering*, 2(12), 2699–2706. https://doi.org/10.1021/sc500440q

Maçaira, P. M., Thomé, A. M.T, Cyrino Oliveira, F. L., & Carvalho Ferrer, A. L. (2018) Time series analysis with explanatory variables: A systematic literature review. *Environmental Modelling & Software*, 107, 199–209. https://doi.org/10.1016/j.envsoft.2018.06.004

Maraveas, C. (2020a) ‘Production of sustainable and biodegradable polymers from agricultural waste’, *Polymers*, 12(5). https://doi.org/10.3390/POLYM12051127

Maraveas, C. (2020b) ‘The sustainability of plastic nets in agriculture’, *Sustainability (Switzerland)*, 12(9). https://doi.org/10.3390/su12093625

Marcelino, P. R. F., Milani, K. M. L., Mali, S., dos Santos, O. J. A. P., and de Oliveira, A. L. M. (2016) Formulations of polymeric biodegradable low-cost foam by melt extrusion to deliver plant growth-promoting bacteria in agricultural systems. *Applied Microbiology and Biotechnology*, 100(16), 7323–7338. https://doi.org/10.1007/s00253-016-7566-9

Martin-Closas, L., Botet, R., and Pelacho, A. M. (2014) An in vitro crop plant ecotoxicity test for agricultural bioplastic constituents. *Polymer Degradation and Stability*, 108, 250–256. https://doi.org/10.1016/j.polymdegradstab.201

Martins, N. C. T., Avellan, A., Rodrigues, S., Salvador, D., Rodrigues, S. M., and Trindade, T. (2020) Composites of Biopolymers and ZnO NPs for Controlled Release of Zinc in Agricultural Soils and Timed Delivery for Maize. *ACS Applied Nano Materials*. https://doi.org/10.1021/acsanm.9b01492

Mastalygina, E., Varyan, I., Kolesnikova, N., Gonzalez, M. I. C., and Popov, A. (2020) Effect of Natural Rubber in Polyethylene Composites on Morphology, Mechanical Properties and Biodegradability. *Polymers*, 12(2), 437. https://doi.org/10.3390/polym12020437
Mate, C. J. and Mishra, S. (2020) ‘Exploring the Potential of Moi Gum for Diverse Applications: A Review’, *Journal of Polymers and the Environment*. Springer US, 28(6), pp. 1579–1591. https://doi.org/10.1007/s10924-020-01709-8

Mejía, J. L., Kerguelén, H., Gil, A., and Gañán, P. (2007) Evaluación de la degradación ambiental de materiales termoplásticos empleados en labores agrícolas en el cultivo de banano en Colombia. *Polímeros*, 17(3), 201–205. https://doi.org/10.1590/s0104-14282007000300008

Michalik, R. and Wandzik, I. (2020) ‘A mini-review on chitosan-based hydrogels with potential for sustainable agricultural applications’, *Polymers*, 12(10), pp. 1–16. https://doi.org/10.3390/polym12102425

Mohammadi-Khoo, S., Moghadam, P. N., Fareghi, A. R., and Movagharnezhad, N. (2015) Synthesis of a cellulose-based hydrogel network: Characterization and study of urea fertilizer slow release. *Journal of Applied Polymer Science*, 133(5). https://doi.org/10.1002/app.42935

Morreale, M., R. Scaffaro, A. Maio, and F. P. La Mantia. (2008) “Mechanical Behaviour of Mater-Bi®/Wood Flour Composites: A Statistical Approach.” *Composites Part A: Applied Science and Manufacturing* 39 (9): 1537–46. https://doi.org/10.1016/j.compositesa.2008.05.015

Mühl, S. and Beyer, B. (2014) ‘Bio-organic electronics—Overview and prospects for the future’, *Electronics*, 3(3), pp. 444–461. https://doi.org/10.3390/electronics3030444

Mujtaba, M., Khawar, K. M., Camara, M. C., Carvalho, L. B., Fraceto, L. F., Morsi, R. E., Elsabee, M.Z., Kaya, M., Labidi, J., Ullah, H., and Wang, D. (2020) Chitosan-based delivery systems for plants: A brief overview of recent advances and future directions. International Journal of Biological Macromolecules. https://doi.org/10.1016/j.ijbiomac.2020.03.128

Mukerabigwi, J. F., Wang, Q., Ma, X., Liu, M., Lei, S., Wei, H., Huang X., and Cao, Y. (2015) Urea fertilizer coated with biodegradable polymers and diatomite for slow release and water retention. *Journal of Coatings Technology and Research*, 12(6), 1085–1094. https://doi.org/10.1007/s11998-015-9703-2

Mukherjee, A., Knoch, S., Chouinard, G., Tavares, J. R., and Dumont, M.-J. (2019) Use of bio-based polymers in agricultural exclusion nets: A perspective. *Biosystems Engineering*, 180, 121–145. https://doi.org/10.1016/j.biosystemseng.2019

Nangia, S., Warkar, S., and Katyal, D. (2019) A review on environmental applications of chitosan biopolymeric hydrogel based composites. *Journal of Macromolecular Science, Part A*, 1–17. https://doi.org/10.1080/10601325.2018.1526041

Narasimhan, S., Srikanth, B. S., and Poltronieri, P. (2016) Plants By-Products and Fibers’ Industrial Exploitation. *Biotransformation of Agricultural Waste and By-Products*, 49–67. https://doi.org/10.1016/b978-0-12-803622-8.00003-3

Niaounakis, M. (2013a) ‘Definitions and Assessment of (Bio)degradation’, *Biopolymers Reuse, Recycling, and Disposal*, pp. 77–94. https://doi.org/10.1016/b978-1-4557-3145-9.00002-6

Niaounakis, M. (2013b) Introduction to Biopolymers. *Biopolymers Reuse, Recycling, and Disposal*, 1–75. https://doi.org/10.1016/b978-1-4557-3145-9.00001-4

Oliveira, M., Mota, C., Abreu, A. S., and Nobrega, J. M. (2015) Development of a green material for horticulture. *Journal of Polymer Engineering*, 35(4). https://doi.org/10.1515/polyeng-2014-0262
Oliveira, T. A., Oliveira, M. I., Mousinho, F. E. P., Barbosa, R., Carvalho, L. H., and Alves, T. S. (2019) Biodegradation of mulch films from poly(butylene adipate co-terephthalate), carnauba wax, and sugarcane residue. Journal of Applied Polymer Science, 48240. https://doi.org/10.1002/app.48240

Oliveira, T. G., Makishi, G. L. A., Chambi, H. N. M., Bittante, A. M. Q. B., Lourenço, R. V., and Sobral, P. J. (2015) Cellulose fiber reinforced biodegradable films based on proteins extracted from castor bean (Ricinus communis L.) cake. Industrial Crops and Products, 67, 355–363. https://doi.org/10.1016/j.indcrop.2015.01.036

Pandey, A. K. and Kumar, A. (2014) ‘Improved microbial biosynthesis strategies and multifarious applications of the natural biopolymer epsilon-poly-l-lysine’, Process Biochemistry. Elsevier Ltd, pp. 496–505. https://doi.org/10.1016/j.procbio.2013.12.009.

Pang, J.-H., Liu, X., Wu, M., Wu, Y.-Y., Zhang, X.-M., and Sun, R.-C. (2014) Fabrication and Characterization of Regenerated Cellulose Films Using Different Ionic Liquids. Journal of Spectroscopy, 2014, 1–8. https://doi.org/10.1155/2014/214057

Perianes-Rodriguez, A., Waltman, L., and Van Eck, N. J. (2016). Constructing bibliometric networks: A comparison between full and fractional counting. Journal of Informetrics, 10(4), 1178–1195. https://doi.org/10.1016/j.joi.2016.10.006

Philip S., Keshavarz T., R. I. (2007) ‘Polyhydroxyalkanoates: Biodegradable polymers with a range of applications’, Journal of Chemical Technology & Biotechnology, 82(May), pp. 233–247. https://doi.org/10.1002/jctb.1667

Plastics Europe 2019 (2019) Annual report 2018, p. 14. Brussels, Belgium: Association of Plastics Manufacturers. Available at: https://www.plasticseurope.org/en/resources/publications/1804-plastics-facts-2019

Puchalski, M., Siwek, P., Panayotov, N., Berova, M., Kowalska, S., and Krucińska, I. (2019) Influence of Various Climatic Conditions on the Structural Changes of Semicrystalline PLA Spun-Bonded Mulching Nonwovens during Outdoor Composting. Polymers, 11(3), 559. https://doi.org/10.3390/polym11030559

Pudelko, A., Postawa, P., Stachowiak, T., Malińska, K., and Dróżdż, D. (2020) Waste derived biochar as an alternative filler in biocomposites - mechanical, thermal and morphological properties of biochar added biocomposites. Journal of Cleaner Production, 123850. https://doi.org/10.1016/j.jclepro.2020.123850

Radovanović, N., Malagurski, I., Lević, S., Gordić, M., Petrović, J., Pavlović, V., Mitrićd M., Nešić A., and Dimitrijević-Branković, S. (2019) Tailoring the physico-chemical and antimicrobial properties of agar-based films by in situ formation of Cu-mineral phase. European Polymer Journal, 119, 352–358. https://doi.org/10.1016/j.europolyjm.2019.08.0

Raghavendra, G. M., Varaprasad, K., and Jayaramudu, T. (2015) Biomaterials. Nanotechnology Applications for Tissue Engineering, 21–44. https://doi.org/10.1016/b978-0-323-32889-0.00002-9

Renner, G., Schmidt, T. C. and Schram, J. (2018) ‘Analytical methodologies for monitoring micro(nano)plastics: Which are fit for purpose?’, Current Opinion in Environmental Science & Health.https://doi.org/10.1016/j.coesh.2017.11.001

Riggi, E., Santagata, G. and Malinconico, M. (2012) ‘Bio-Based and Biodegradable Plastics for Use in Crop Production’, Recent Patents on Food, Nutrition & Agriculture, 3(1), pp. 49–63. https://doi.org/10.2174/2212798411103010049
Rocha, D. B., Souza de Carvalho, J., de Oliveira, S. A., & dos Santos, R.D. (2018) A new approach for flexible PBAT/PLA/CaCO3 films into agriculture. Journal of Applied Polymer Science, 135(35), 46660. https://doi.org/10.1002/app.46660

Romero, L. and Portillo, S.E. (2019) ‘Trends in sigma-1 receptor research: A 25-year bibliometric analysis’, Frontiers in Pharmacology, 10(MAY), pp. 1–17. https://doi.org/10.3389/fphar.2019.00564

Rudin, A., and Choi, P. (2013) Biopolymers. The Elements of Polymer Science & Engineering, 521–535. https://doi.org/10.1016/b978-0-12-382178-2.00013-4

Rujnić-Sokele, M., and Pilipović, A. (2017) Challenges and opportunities of biodegradable plastics: A mini review. Waste Management & Research, 35(2), 132–140. https://doi.org/10.1177/0734242x16683272

Saallah, S. and Lenggoro, I. W. (2018) ‘Nanoparticles carrying biological molecules: Recent advances and applications’, KONA Powder and Particle Journal, 2018(35), pp. 89–111. https://doi.org/10.14356/kona.2018015

Saaba, N., Jawaid, M., and Al-Othman, O. (2017) An Overview on Polylactic Acid, its Cellulosic Composites and Applications. Current Organic Synthesis, 14(2), 156–170. https://doi.org/10.2174/1570194136661609211

Santos, N.L., Ragazzo, G.O., Cerri, B.C., Soares, M.R., Kieckbusch, T.G., and da Silva, M.A. (2020) ‘Physicochemical properties of konjac glucomannan/alginate films enriched with sugarcane vinasse intended for mulching applications’. International Journal of Biological Macromolecules. Elsevier B.V., 165, pp. 1717–1726. https://doi.org/10.1016/j.ijbiomac.2020.10.049

Sapuan, S. M. (2017) Materials Selection for Composites: Concurrent Engineering Perspective, Composite Materials. https://doi.org/10.1016/b978-0-12-802507-9.00006-4

Saratale, R. G., Saratale, G. D., Shin, H. S., Jacob, J. M., Pugazhendhi, A., Bhaisare, M., and Kumar, G. (2017). New insights on the green synthesis of metallic nanoparticles using plant and waste biomaterials: current knowledge, their agricultural and environmental applications. Environmental Science and Pollution Research, 25(11), 10164–10183. https://doi.org/10.1007/s11356-017-9912-6

Sartore, L., Bignotti, F., Pandini, S., D’Amore, A., and Di Landro, L. (2015) Green composites and blends from leather industry waste. Polymer Composites, 37(12), 3416–3422. https://doi.org/10.1002/pc.23541

Sartore, L., Schettini, E., Pandini, S., Bignotti, F., Vox, G., and D’Amore, A. (2016) Biodegradable containers from green waste materials. AIP Conference Proceedings; https://doi.org/10.1063/1.4949675

Sartore, L., Schettini, E., de Palma, L., Brunetti, G., Cocozza, C., and Vox, G. (2018) Effect of hydrolyzed protein-based mulching coatings on the soil properties and productivity in a tunnel greenhouse crop system. Science of The Total Environment, 645, 1221–1229. https://doi.org/10.1016/j.scitotenv.2018.07.259

Sartore, L., Vox, G., and Schettini, E. (2013) Preparation and Performance of Novel Biodegradable Polymeric Materials Based on Hydrolyzed Proteins for Agricultural Application. Journal of Polymers and the Environment, 21(3), 718–725. https://doi.org/10.1007/s10924-013-0574-2
Scarascia-Mugnozza, G., Sica, C., and Russo, G. (2012) ‘Plastic Materials in European Agriculture: Actual Use and Perspectives’, *Journal of Agricultural Engineering*, 42(3), p. 15. https://doi.org/10.4081/jae.2011.3.15

Schettini, E., Santagata, G., Malinconico, M., Immirzi, B., Scarascia Mugnozza, G., and Vox, G. (2013) Recycled wastes of tomato and hemp fibres for biodegradable pots: Physico-chemical characterization and field performance. *Resources, Conservation and Recycling*, 70, 9–19. https://doi.org/10.1016/j.resconrec.2012.11.002

Scott, G. (2002) ‘Why Degradable Polymers?’, *Degradable Polymers*, pp. 1–15. https://doi.org/10.1007/978-94-017-1217-0_1

Seuring, S., and Gold, S. (2012) Conducting content-analysis based literature reviews in supply chain management. *Supply Chain Management: An International Journal*, 17(5), 544–555. https://doi.org/10.1108/13598541211258609

Sforzini, S., Oliveri, L., Chinaglia, S., and Viarengo, A. (2016) Application of Biotests for the Determination of Soil Ecotoxicity after Exposure to Biodegradable Plastics. *Frontiers in Environmental Science*, 4. https://doi.org/10.3389/fenvs.2016.00068

Sharif, R., Mujtaba, M., Ur Rahman, M., Shalmani, A., Ahmad, H., Anwar, T., Tianchan D., and Wang, X. (2018) The Multifunctional Role of Chitosan in Horticultural Crops; A Review. *Molecules*, 23(4), 872. https://doi.org/10.3390/molecules23040872

Sharma, K., Kumar, V., Kaith, B. S., Kumar, V., Som, S., Kalia, S., and Swart, H. C. (2014) A study of the biodegradation behaviour of poly(methacrylic acid/aniline)-grafted gum ghatti by a soil burial method. *RSC Advances*, 4(49), 25637. https://doi.org/10.1039/c4ra03765k

Sharma, R., Bajpai, J., Bajpai, A. K., Acharya, S., Kumar, B., and Singh, R. K. (2017) Assessment of Water Retention Performance of Pectin-Based Nanocarriers for Controlled Irrigation in Agriculture. *Agricultural Research*, 6(2), 139–149. https://doi.org/10.1007/s40003-017-0257-7

Shen, M., Song, B., Zeng, G., Zhang, Y., Huang, W., Wen, X., and Tang, W. (2020) Are biodegradable plastics a promising solution to solve the global plastic pollution? *Environmental Pollution*, 263, 114469. https://doi.org/10.1016/j.envpol.2020.114469

Shih, I. and Shen, M. (2006) ‘Microbial synthesis of poly ( e -lysine ) and its various applications’, *Bioresource Technology*, 97(9), 1148–1159. https://doi.org/10.1016/j.biortech.2004.08.012

Simões, B. M., Cagnin, C., Yamashita, F., Olivato, J. B., Garcia, P. S., de Oliveira, S. M., and Eiras Grossmann, M. V. (2019) Citric acid as crosslinking agent in starch/xanthan gum hydrogels produced by extrusion and thermopressing. *LWT*, 108950. https://doi.org/10.1016/j.lwt.2019.108950

Singh A., Sarkar D.J., Singh A.K., Parsad R., and Kumar A., P. B. S. (2011) ‘Studies on novel nanosuperabsorbent composites: Swelling behavior in different environments and effect on water absorption and retention properties of sandy loam soil and soil-less medium’, *Journal of Applied Polymer Science*, 120(3), pp. 1448–1458. https://doi.org/10.1002/app.33263

Siracusa, V., Rocculi, P., Romani, S., and Rosa, M. D. (2008) Biodegradable polymers for food packaging: a review. *Trends in Food Science & Technology*, 19(12), 634–643. https://doi.org/10.1016/j.tifs.2008.07.003

Siwek, P., Libik, A., Twardowska, S.K., Ciechska, D., and Gryza, I. (2010) ‘Biopolymers and their applications in agriculture’, *Polimery*, 55(11/12), pp. 806–811. https://doi.org/10.14314/polimery.2010.806
Skrzypczak, D., Witek-Krowiak, A., Dawiec-Liśniewska, A., Podstawczyk, D., Mikula, K., and Chojnacka, K. (2019) Immobilization of biosorbent in hydrogel as a new environmentally friendly fertilizer for micronutrients delivery. *Journal of Cleaner Production*, 118387. https://doi.org/10.1016/j.jclepro.2019.118387

Stoykov, Y. M., Pavlov, A. I. and Krastanov, A. I. (2015) ‘Chitinase biotechnology: Production, purification, and application’, *Engineering in Life Sciences*, 15(1), pp. 30–38. https://doi.org/10.1002/elsc.201400173

Tachibana, Y., Maeda, T., Ito, O., Maeda, Y., and Kunioka, M. (2009) Utilization of a Biodegradable Mulch Sheet Produced from Poly(Lactic Acid)/Ecoflex®/Modified Starch in Mandarin Orange Groves. *International Journal of Molecular Sciences*, 10(8), 3599–3615. https://doi.org/10.3390/ijms10083599

Tan, B.K., Ching, Y., Gan, S., and Rozali, S. (2015) Biodegradable Mulches Based on Poly(vinyl Alcohol), Kenaf Fiber, and Urea. *BioResources*, 10(3), 5532-5543. Available at: https://ojs.cnr.ncsu.edu/index.php/BioRes/article/view/BioRes_10_3_5532_Tan_Biodegradable_Mulches_Kenaf_Fiber_Urea

Timilsena, Y. P., Adhikari, R., Casey, P., Muster, T., Gill, H., and Adhikari, B. (2014) Enhanced efficiency fertilisers: a review of formulation and nutrient release patterns. *Journal of the Science of Food and Agriculture*, 95(6), 1131–1142. https://doi.org/10.1002/jsfa.6812

Thomé, A. M. T., Scavarda, L. F., and Scavarda, A. J. (2016) Conducting systematic literature review in operations management. *Production Planning & Control*, 27(5), 408–420. https://doi.org/10.1080/09537287.2015.1129464

Touchaleaume, F., Martin-Closas, L., Angellier-Coussy, H., Chevillard, A., Cesar, G., Gontard, N., and Gastaldi, E. (2016) Performance and environmental impact of biodegradable polymers as agricultural mulching films. *Chemosphere*, 144, 433–439. https://doi.org/10.1016/j.chemosphere.2015.09

Tudor, V. C., Smedescu, D.I.S, Fîntîneru, G., Fîntîneru, A., Marcuta, A., and Iova, R.A. (2019) ‘Plasticulture: Diffusion of plastic materials in the agricultural sector’, *Materiale Plastice*, 56(2), pp. 730–734. https://doi.org/10.37358/mp.19.4.5260

Vaca-Garcia, C. (2008) ‘Biomaterials’, *Introduction to Chemicals from Biomass*. John Wiley & Sons, Ltd, pp. 103–142. https://doi.org/10.1002/9780470697474.ch5

Vaicekauskaite, J., Ostrauskaite, J., Treinyte, J., Grazuleviciene, V., Bridziuviene, D., and Rainosalo, E. (2018) Biodegradable Linseed Oil-Based Cross-Linked Polymer Composites Filled with Industrial Waste Materials for Mulching Coatings. *Journal of Polymers and the Environment*. https://doi.org/10.1007/s10924-018-1360-y

Van Eck, N.J. and Waltman, I. (2014) Measuring Scholarly Impact, *Measuring Scholarly Impact*. https://doi.org/10.1007/978-3-319-10377-8

Van Eck, N. J. and Waltman, L. (2009a) ‘How to normalize cooccurrence data? An analysis of some well-known similarity measures’, *Journal of the American Society for Information Science and Technology*, 60(8), pp. 1635–1651. https://doi.org/10.1002/asi.21075

Van Eck, N. J., and Waltman, L. (2009b) Software survey: VOSviewer, a computer program for bibliometric mapping. *Scientometrics*, 84(2), 523–538. https://doi.org/10.1007/s11192-009-0146-3
Vázquez-Morillas, A., Beltrán-Villavicencio, M., Alvarez-Zeferino, J. C., Osada-Velázquez, M. H., Moreno, A., Martínez, L., and Yañez, J. M. (2016) Biodegradation and Ecotoxicity of Polyethylene Films Containing Pro-Oxidant Additive. *Journal of Polymers and the Environment, 24*(3), 221–229. https://doi.org/10.1007/s10924-016-0765-8

Velásquez, C. L. (2008) ‘Algunas potencialidades de la quitina y el quitosano para usos relacionados con la agricultura en Latinoamerica’, *Revista Cientifica UDO Agricola*, 8(1), pp. 1–22. Available at: http://www.bioline.org.br/pdf/cg08002

Verma, D. and Fortunati, E. (2019) Biobased and biodegradable plastics, *Handbook of Ecomaterials*. https://doi.org/10.1007/978-3-319-68255-6_103

Verma, M. L., Dhanya, B. S., Sukriti, Rani, V., Thakur, M., Jeslin, J., and Kushwaha, R. (2020) Carbohydrate and protein based biopolymeric nanoparticles: Current status and biotechnological applications. *International Journal of Biological Macromolecules*. https://doi.org/10.1016/j.ijbiomac.2020.03.10

Versino, F., Urriza, M. and García, M. A. (2020) ‘Cassava-based biocomposites as fertilizer controlled-release systems for plant growth improvement’, *Industrial Crops and Products*. Elsevier, 144(May 2019), p. 112062. https://doi.org/10.1016/j.indcrop.2019.112062

Vinceković, M., Jurić, S., Dermić, E., and Topolovec-Pintarić, S. (2017) Kinetics and Mechanisms of Chemical and Biological Agents Release from Biopolymeric Microcapsules. *Journal of Agricultural and Food Chemistry, 65*(44), 9608–9617. https://doi.org/10.1021/acs.jafc.7b04075

Vroman, I. and Tighzert, L. (2009) ‘Biodegradable polymers’, *Materials, 2*(2), pp. 307–344. https://doi.org/10.3390/m2020307

Wadsworth, L. C., Hayes, D. G., Wszelaki, A. L., Washington, T. L., Martin, J., Lee, J., Raley R., Pannell T., Dharmalingam S., Miles, C., Saxton, A., and Inglis, D. A. (2013) Evaluation of Degradable Spun-Melt 100% Polylactic Acid Nonwoven Mulch Materials in a Greenhouse Environment. *Journal of Engineered Fibers and Fabrics, 8*(4), 155892501300800. https://doi.org/10.1177/155892501300800414

Wang, W., and Wang, A. (2009) Synthesis, swelling behaviors, and slow-release characteristics of a guar gum-g-poly(sodium acrylate)/sodium humate superabsorbent. *Journal of Applied Polymer Science, 112*(4), 2102–2111. https://doi.org/10.1002/app.29620

Wang, W., Yang, S., Zhang, A., and Yang, Z. (2020) ‘Preparation and properties of novel corn straw cellulose–based superabsorbent with water-retaining and slow-release functions’, *Journal of Applied Polymer Science, 137*(32), pp. 1–12. https://doi.org/10.1002/app.48951

Wortman, S. E., Kadoma, I. and Crandall, M. D. (2015) ‘Assessing the potential for spunbond, nonwoven biodegradable fabric as mulches for tomato and bell pepper crops’, *Scientia Horticulturae*. Elsevier B.V., 193, pp. 209–217. https://doi.org/10.1016/j.scienta.2015.07.019

Wortman, S. E., Kadoma, I. and Crandall, M. D. (2016) ‘Biodegradable plastic and fabric mulch performance in field and high tunnel cucumber production’, *HortTechnology, 26*(2), pp. 148–155. https://doi.org/10.21273/horttech.26.2.148

Wróblewska-Krepsztul, J., Rydzkowski, T., Borowski, G., Szczypiński, M., Klepka, T., and Thakur, V. K. (2018) Recent progress in biodegradable polymers and nanocomposite-based packaging materials for sustainable environment. *International Journal of Polymer Analysis and Characterization, 23*(4), 383–395. https://doi.org/10.1080/1023666X.2018.1455382
Wyatt, V. T. and Yadav, M. (2013) ‘A multivariant study of the absorption properties of poly(glutaric
acid-glycerol) films’, Journal of Applied Polymer Science, 130(1), pp. 70–77. https://doi.org/10.1002/app.39034

Xie, J., Yang, Y., Gao, B., Wan, Y., Li, Y. C., Cheng, D., Xiao, T., Li, K., Fu, Y., Xu, J., Zhao, Q.,
Zhang, Y., Tang, Y., Yao, Y., Wang, Z., and Liu, L. (2019) Magnetic-Sensitive Nanoparticle
Self-Assembled Superhydrophobic Biopolymer-Coated Slow-Release Fertilizer: Fabrication,
Enhanced Performance and Mechanism. ACS Nano. https://doi.org/10.1021/acsnano.8b09197

Yang, S.-R., and Wu, C.-H. (1999) Degradable plastic films for agricultural applications in Taiwan.
Macromolecular Symposia, 144(1), 101–112. https://doi.org/10.1002/masy.19991440110

Yang, Y., Tong, Z., Geng, Y., Li, Y., and Zhang, M. (2013) Biobased Polymer Composites Derived
from Corn Stover and Feather Meals as Double-Coating Materials for Controlled-Release and
Water-Retention Urea Fertilizers. Journal of Agricultural and Food Chemistry, 61(34), 8166–
8174. https://doi.org/10.1021/jf402519t

Yin, J., Wang, H., Yang, Z., Wang, J., Wang, Z., Duan, L., Li, Z., and Tan, W. (2020) Engineering
Lignin Nanomicroparticles for the Antiphotolysis and Controlled Release of the Plant Growth
Regulator Abscisic Acid. Journal of Agricultural and Food Chemistry. https://doi.org/10.1021/
acs.jafc.0c02835

Zainescu, G., Albu, L., Deselnicu, D., Constantinescu R., Vasilescu A., Nichita P., and Sirbu, C.
(2014) ‘A new concept of complex valorization of leather wastes’, Materiale Plastice, 51(1),
pp. 90–93. Available at: https://www.revmaterialeplastice.ro/pdf/ZAINESCU G.pdf 1 14.pdf

Zhang, J., Yu, Q., Zheng, F., Long, C., Lu, Z., and Duan, Z. (2015) Comparing keywords plus of WOS
and author keywords: A case study of patient adherence research. Journal of the Association for
Information Science and Technology, 67(4), 967–972. https://doi.org/10.1002/asi.23437