EDITORA VERDE
Revista Verde
de Agroecologia e Desenvolvimento Sustentável
Green Journal of Agroecology and Sustainable Development
GVAA GRUPO VERDE DE AGROECOLOGIA E ABELHAS

Composting plants as a technology for the transformation of agro-industrial residue into organic fertilizer

Usinas de compostagem como tecnologia para a transformação de resíduo agroindustrial em adubo orgânico

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REVIEW
Received: 11-08-2022
Accepted: 27-10-2022

Key words:
Biofertilizer
Environment
Organic residue

ABSTRACT

The increase in the consumption of ready-to-eat foods has also increased the generation of agro-industrial waste. The organic matter present in these residues causes damage to the environment when they are improperly disposed of. Composting is a technology that uses these residues to obtain a sustainable material that can be used as a biofertilizer, without harming the environment. The objective was to collect and analyze data related to composting as a technology capable of transforming agro-industrial waste into organic fertilizer. For this, keywords were defined and a survey of information in the SciELO database was carried out. The keyword [composting AND ("agro-industrial waste" OR "agro-industrial waste")], in English, obtained the best representation and refinement. Annual evolution data were observed between 2007 and 2020, with the number of publications fluctuating over the period. Considering the 13 selected scientific articles, a total of 4 countries were highlighted as the headquarters of the research executing institutions, namely: Brazil, Chile, Mexico and Portugal. The thematic area "Agrarian Sciences" and the journal "Engenharia Agrícola" have the largest number of publications in their respective groups. There was no relationship between the number of publications of scientific articles and the impact factor presented by the journal. The relevance of the control of humidity, aeration, temperature, pH, carbon and nitrogen ratio (C:N) and granulometry was verified. Therefore, composting is a potential technology to transform agro-industrial waste into organic fertilizer.

Palavras-chave:
Biofertilizante
Meio ambiente
Resíduo orgânico

RESUMO

O aumento do consumo de alimentos prontos também aumentou a geração de resíduos agroindustriais. A matéria orgânica presente nesses resíduos causa danos ao meio ambiente, quando são descartados de forma inadequada. A compostagem é uma tecnologia que utiliza esses resíduos para obter um material sustentável, que pode ser utilizado como biofertilizantes sem agredir o meio ambiente. O objetivo foi coletar e analisar dados relacionados à compostagem como tecnologia capaz de transformar resíduos agroindustriais em adubo orgânico. Para isso, foram definidas palavras-chave e realizado um levantamento de informações na base de dados SciELO. A palavra-chave [composting AND ("agro-industrial waste" OR "agro-industrial waste")], na língua inglesa, obteve a melhor representatividade e refinamento. Os dados de evolução anual foram observados entre 2007 e 2020, com o número de publicações flutuando ao longo do período. Considerando os 13 artigos científicos selecionados, um total de 4 países foram destacados como sede das instituições executoras da pesquisa, a saber: Brasil, Chile, México e Portugal. A área temática "Ciências Agrárias" e o periódico "Engenharia Agrícola" apresentam o maior número de publicações em suas respectivas turmas. Não houve relação entre o número de publicações de artigos científicos e o fator de impacto apresentado pela revista. Verificou-se a relevância do controle da umidade, aeração, temperatura, pH, razão carbono e nitrogênio (C:N) e granulometria. Portanto, a compostagem é uma tecnologia potencial para transformar resíduos agroindustriais em adubo orgânico.

INTRODUCTION

The demand for ready-to-eat or ready-to-eat foods has increased considerably in recent years. The revolution in food habits and the multiple industrial advances in the food area resulted in the generation of tons of agro-industrial waste (MONTEIRO, 2016). The lack of control and correct destination for the recycling of organic waste has made Brazil one of the countries that generate the most waste (FELICORI et al., 2016; LOPES SOBRINHO et al., 2017). Organic solid waste naturally has a high value of organic matter and causes harm to the environment when improperly disposed of. The destination and recycling of these wastes are still flaws, especially on a large scale, such as industrial. However, these residues have biodegradable characteristics, in addition to having a high moisture value, enabling their destination for recycling techniques that value this by-(CZAPELA et al., 2020).

Composting is one of the recycling techniques that can be applied to organic waste. The composting process occurs with the controlled decomposition of plant remains, resulting in a material similar to organic soil (BUSS; MORETO, 2019). During the composting process, the organic residue components are released, such as nitrogen, phosphorus, potassium and microelements that increase the yield of the plants, ending the process with a substrate of high chemical, physical and biological value, which can be used as fertilizer (PIRES; FERRÃO, 2017). Composting can be classified according to biology, temperature, environment and process. The process can be done by the natural and accelerated methods, according to the characteristics for the transformation of the organic mass (SILVA et al., 2020). Three types of composting commonly used can be mentioned: natural (the material is arranged in windrows, in which mixing and, eventually, humidification is carried out, until the end of the process); forced aeration (does not need mixing of the material, as it is deposited in a perforated pipe system that will perform the aeration) and biological reactor (closed environment, which allows the control of parameters without interference from the external environment) (BRINCK, 2020).

Some physical and chemical parameters influence the composting process, being necessary to analyze factors such as temperature, humidity, pH, carbon and nitrogen ratio (C:N), aeration, granulometry, size of the windrows and the microorganisms involved in the process (SOUZA et al., 2020). To increase the cycling of organic matter in cities and/or industries and reduce environmental impacts, large-scale composting, such as plants, shows greater feasibility. Composting plants involve complex processes and require specific facilities: patio, equipment and drainage systems to capture the leachate produced by the windrows in the process of material degradation, sending it to treatment plants (SILVA et al., 2020).

However, no records were found in the literature on scientific prospecting that help in the direction, planning and maturation of innovative strategies on the composting process as a technology for the transformation of agro-industrial waste. From this perspective, the objective of this scientific survey was to elucidate the scientific articles that approach composting plants as a technology for the transformation of agro-industrial waste into organic fertilizer, exploring the general characteristics, annual evolution, correlation of countries and institutions of research execution, ranking of thematic areas of publication, periodicals and their respective countries of origin. It is also intended to provide a set of information on the composting technology steps (i), conditions for treatment by composting (ii) and reports of selected articles (iii).

MATERIAL AND METHODS

Information sources

The approach of this brief scientific prospection was quantitative and exploratory based on bibliographic research. The Scientific Electronic Library Online (SciELO) database was selected as a source of information. SciELO is a cooperative electronic portal of open access scientific journals in Latin America. No contact was made with authors to identify additional studies.

Search strategies

The search protocol was adapted according to Tenório et al. (2017) e Feitosa et al. (2021). Searches were carried out on April 18 and 19, 2021 on composting plants as a technology for transforming agro-industrial waste into organic fertilizer. No time restriction was applied, proceeding with searches for keywords or descriptors in Portuguese and English, as well as in singular and plural (Table 1).

Table 1. Keywords selected in each language for searches in the SciELO database.

N.	Languages	
	Portuguese	English
1	compostagem OR “reciclagem orgânica”	composting OR “organic recycling”
2	compostagem AND (resíduo OR resíduos)	composting AND (waste OR residue)
3	compostagem AND agroindust*	composting AND agroindustr*
4	compostagem AND (“resíduo industrial” OR “resíduos industriais”)	composting AND (“industrial waste” OR “industrial residue” OR “industrial wastes” OR “industrial residues”)
5	compostagem AND (“resíduo agrícola” OR “resíduos agrícolas”)	composting AND (“agricultural waste” OR “agricultural residue” OR “agricultural wastes” OR “agricultural residues”)
6	compostagem AND (“resíduo agroindustrial” OR “resíduos agroindustriais”)	composting AND (“agro-industrial waste” OR “agroindustrial waste” OR “agroindustry waste” OR “agro-industrial residue” OR “agroindustrial residue” OR “agroindustry residue” OR “agro-industrial wastes” OR “agroindustrial wastes” OR “agroindustry wastes” OR “agro-industrial residues” OR “agroindustrial residues” OR “agroindustry residues”)

*truncation coordinate.

The "advanced searches" mode was used, with attention to the supported characters and their particularities in the journal base. Filters were used to include publications of scientific articles and reviews, and publications in scientific events, technical books, monographs, dissertations, theses and others were discarded.

Data Processing

For the final treatment of the data, the keyword and language with the best qualitative representation and the best refinement were considered. The results obtained were analyzed in terms of general characteristics, annual evolution, correlation of countries and institutions of research execution, ranking of thematic areas of publication, journals and their respective countries of origin, with the highest numbers of published scientific articles. Scientific articles of interest were also searched in the available literature on the topic under study. Information on the composting technology steps (i); conditions for treatment by composting (ii) and reports of selected articles (iii) were explored. The representation was performed in tables or plotted the results in figures, using Microsoft® Office Excel 2013.

RESULTS AND DISCUSSION

Study of general characteristics

The refinement trend increased from keyword 1 to number 5 (Table 1). Search strategies containing English keywords retrieved a larger number of articles, given the international nature of this language. The keyword [composting AND ("agro-industrial waste" OR "agro-industrial waste")], in the English language, obtained the best representation and refinement. The keyword designated as number 6 indicated substantial results that were more specific and adequate to the object of study, indicating the greatest variation in the possibility of terms. Therefore, 13 scientific articles were included as the main sample in the selection of this study.

Annual evolution

The annual evolution of publications of scientific articles in the SciELO database, referring to the keyword [composting AND ("agroindustrial waste" OR "agroindustrial waste")], in English, was expressed in Figure 1.

Annual evolution data were observed between 2007 and 2020, with the number of publications fluctuating throughout the period. The peak of publications was highlighted in the years 2018 and 2020, with 3 scientific articles published, being 3 times greater than the numbers observed in the years 2007, 2010 and 2013. In the years 2008, 2011-12, 2014-15, 2017 and 2019 there were no publications on the aforementioned topic. Therefore, it is not possible to determine exactly a trend of publications.

The first research found focused on the toxicity of the organic compost obtained from composting. Subsequent research focused on the application of composting to specific organic materials, of plant or animal origin, also aiming at obtaining fertilizer for agricultural purposes. Few researches aimed at technical improvement (reduction of composting time without affecting the quality and safety of the organic fertilizer obtained) are available. In this sense, new studies that help to improve the efficiency of the process are encouraged, since composting is a technique that demands a lot of time. In general, it is clear that the number of scientific publications increased during the period studied, but it is still considerably low. More research to help solve the environmental problem generated by agro-industrial waste is urgently needed.

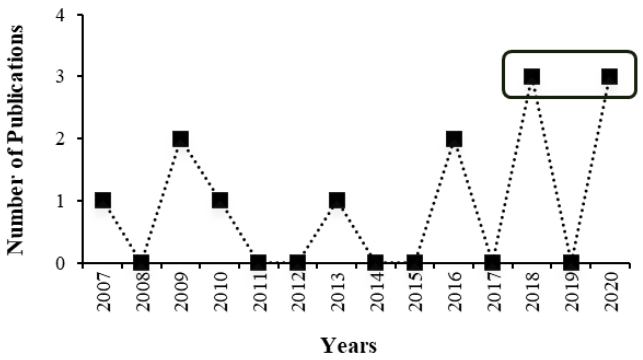

Figure 1. Annual evolution of publications of scientific articles in the SciELO database, referring to the keyword: composting AND ("agro-industrial waste" OR "agro-industrial waste"), in English.

Correlation of countries and research institutions

Figure 2 shows the correlation of countries and institutions that carry out research developed through a search in the SciELO database, referring to the keyword [composting AND ("agro-industrial waste" OR "agro-industrial waste")], in English.

Considering the 13 selected scientific articles, a total of 4 countries were highlighted as the headquarters of the research execution institutions, namely: Brazil, Chile, Mexico and Portugal. Brazil held 70% of publications in relation to other countries. Of this total, there was a concentration of scientific articles published by the State University of Western Paraná (UNOESTE), with exactly 67% ($n = 6$). Among the UNOESTE articles, more than half refer to a specific research group (Research Group on Water Resources and Environmental Sanitation). In their research, the group holds most of the works that involve process efficiency, for example, by evaluating the effect of windrow coverage on composting time and evaluation

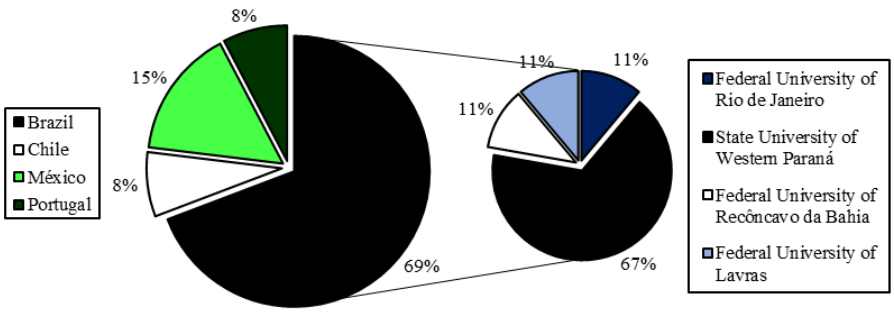

Figure 2. Correlation of countries and institutions carrying out research obtained through the SciELO database, referring to the keyword: composting AND ("agro-industrial waste" OR "agro-industrial waste"), in English.

of microbial and enzymatic activity during composting (COSTA et al., 2016; BERNARDI et al., 2018). At the national level, research predominantly seeks the application of composting in organic waste from specific branches of agribusiness and the evaluation of the organic fertilizer obtained.

Ranking of thematic areas, journals and countries of origin

The results of searches carried out in the SciELO database for the ranking of thematic areas, journals and countries of origin with the highest numbers of published scientific articles are shown in Table 2.

In the ranking of thematic areas, a publication exclusivity was observed in the topics "Agrarian Sciences" (76.92%), "Engineering" (15.38%) and "Biological Sciences" (7.69%), which is consistent with the topic under study about composting plants as a technology for the transformation of agro-industrial waste into organic fertilizer. In this sense, the journals identified mostly have the scope related to the main thematic areas. There was no relationship between the publication number of scientific articles and the impact factor presented by the journal, in addition to the fact that the impact factor of the journals "Engenharia Agrícola" and "Ciencia e Investigación Agraria" was not identified, the first being the one that indicated a higher percentage of scientific articles (23.08%, n = 3). In this sense, Brazil was the country of origin of most of the journals selected by the authors for the publication of their research, with 53.85% (n = 7). Then, Chile, Colombia, Mexico and Portugal were the countries with the highest number of publications, being consistent and similar with the countries of the research execution institutions in Figure 2.

Table 2. Top of the thematic areas, journals and countries of origin with the highest numbers of published scientific articles.

Ranking	Names	Numbers	%	Impact factor[1]
Thematic areas				
1	Agricultural Sciences	10	76.92	
2	Engineering	2	15.38	
3	Biological Sciences	1	7.69	
Total		13	100.00	
Journals				
1	Engenharia Agrícola	3	23.08	ND
2	Revista Brasileira de Engenharia Agrícola e Ambiental	2	15.38	0.654
3	Brazilian Journal of Microbiology[2]	1	7.69	2.428
4	Ciencia e Investigación Agraria	1	7.69	ND
5	Others	6	46.15	
Total		13	100.00	
Countries of origin				
1	Brazil	7	53.85	
2	Chile	3	23.08	
3	Colombia	1	7.69	
4	Mexico	1	7.69	
5	Portugal	1	7.69	
Total		13	100.00	

[1]Journal Citation Reports 2019. [2]This journal has been discontinued from the SciELO collection. ND – unidentified

Composting technology steps

Figure 3 shows the adapted flowchart applicable to any solid waste composting process. This method may vary depending on the type of compost.

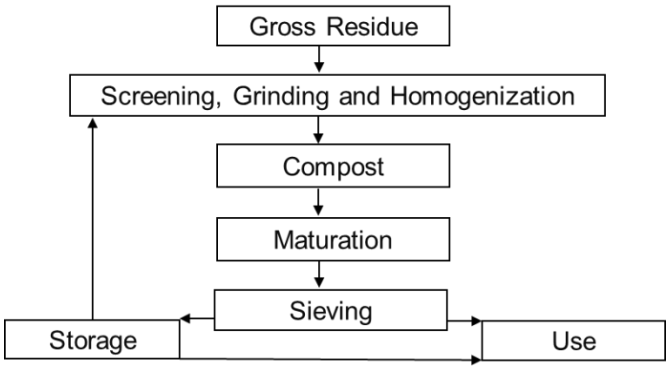

Figure 3. General flowchart of solid waste composting. Source: adapted from Schaub and Leonard (2005).

Gross waste

The first step in starting a composting process is choosing the raw waste to be used. For this, it is necessary to opt for a residue with organic material generated in sufficient quantities to justify the implementation of the technique. The choice can be made by analyzing the gravimetric composition of solid waste generated by a certain activity (BOSCO, 2017). Gravimetric analysis is able to estimate the amounts of each type of waste, whether recyclable, organic or tailings, observing the amount in contribution of each of them in the organic phase. The greater the contribution, the greater its potential in composting (COSTA FILHO et al., 2020).

The characteristics of the solid residue chosen are extremely important, especially the humidity, since the composters need appropriate amounts of water in the medium to develop and degrade the organic matter. A humidity range between 40 and 60% is recommended. Much lower humidity inhibits biological activity, while much higher humidity makes composting difficult – such as waste from sanitary sewage, animal hygiene and industrial effluents, which have very high humidity. In these cases, anaerobic processes such as biodigesters are recommended (WOJAHN, 2016).

Screening, grinding and homogenization

The organic materials chosen are usually sorted according to type and arranged along a belt, where the recyclable materials will be properly stored and separated for composting. The conveyor must be suitable for the materials, enabling their transport to the next sector, which may include drums and pumps (ROLDÃO; ROLDÃO, 2018). The crushing step can be applied before homogenization, depending on the nature of

the material, as in cases of very resistant residues. Subsequently, the selected residue is placed in an appropriate container and mixed, manually or mechanically, in order to be homogenized, being later weighed to obtain a total value of the sample weight (COSTA FILHO et al., 2020).

Composting

After weighing, the material goes to composting itself. The area selected for the construction of the piles must have ample space and be easily accessible. Stacks are built in two layers. The first layer is dry plant material containing leaves and branches to absorb excess water and allow air to circulate, being watered only to promote moistening. The second layer is made with selected organic material such as food scraps, grass and manure (TONINI et al., 2020).

The composting process is divided into four phases. The initial phase occurs with the decomposition of organic matter and the proliferation of mesophilic microorganisms takes place, which will raise the temperature to 45 °C for 15 to 72 hours. The second phase is thermophilic, characterized by high oxygen consumption by thermophilic microorganisms and a gradual increase in temperature up to 70 °C. At this temperature, pathogenic microorganisms are eliminated and pH decreases (BRASIL, 2017). The third phase is the mesophilic. In this phase, the thermophilic population is restricted and the temperature is reduced to 45 °C, causing the mesophilic population to settle again. In natural composting, this stage lasts between 60 to 90 days. The fourth and final stage is maturation. At maturation, most of the organic material has already been transformed, the temperature and pH have already been stabilized, forming humus, a nutrient-rich compound that is easily absorbed by the roots (BRINCK, 2020).

Screening, storage and use

A portion of inorganic material may remain after the composting process has ended. For this reason, sieving with rotary sieves is performed to remove this inorganic portion, which can impair the quality of the final product (BOSCO, 2017). The material resulting from composting is stored according to the characteristics of the material. If it is slurry, also known as biofertilizer, it can be stored in containers that contain faucets. Organic fertilizer, known as humus, is kept in a container with the entire volume filled. Zanta et al. (2017) found that the Bag was the container with the highest storage capacity, but in terms of system operation, the round container was better suited for everyday use.

Conditions for treatment by composting

Humidity, aeration and temperature

Water is very important in this process. Without water, microorganisms cannot reproduce. To carry out the composting process, a balance between water and air is essential, with a recommended range between 40 and 60%. (WOJAHN, 2016; ROSA et al., 2020). The compost must be sufficiently aerated. The amount of oxygen needed depends on the stage of the process, the type of waste and the particle size. The absence of oxygen can result in a reduction in the activity of aerobic microorganisms and an increase in anaerobes, causing the process to be slower and releasing more unpleasant odors (CORREA; RICCI, 2016).

The temperature in the composting process is a determining factor for the growth of microorganisms involved in the process, their thermophilic and mesophilic phases. It will also be used as a reference for the evolution of the process, and must be measured daily. The absence of heat at the beginning of composting represents that the process was inefficient. In order to know when the process comes to an end, the temperature must be constant (HECK et al., 2013; PEDROSA et al., 2013).

pH, carbon and nitrogen ratio (C:N) and particle size

Composting uses organic compounds, whose pH variation directly influences the cation retention capacity. The most appropriate pH for composting is between 5.5 and 8.0, as bacteria prefer values close to 7.0. The decrease in pH means that there was an increase in the amount of CO2 and organic acids produced by microbiological activity, reducing the efficiency and increasing the process time (DORES-SILVA et al., 2013; LOPES SOBRINHO et al., 2017).

Carbon and nitrogen are important nutrients used by microorganisms in composting. The relationship between the two directly influences the microbial activity and, consequently, the decomposition time. Nitrogen is used by microorganisms to form proteins, especially microbial DNA and RNA, while carbon is a source of energy to form their structures. The higher the carbon/nitrogen ratio (C/N), the longer the decomposition time of the material (CARLESSO et al., 2011; PEDROSA et al., 2016). Particle size is essential to avoid formation of aggregates in the solid material of the dough. Very fine and small particles cause greater compaction of the material, making it difficult to decompose. It is recommended that particles between 1 and 5 cm in diameter are used (BRINCK, 2020).

Reports of selected articles

Varnero et al. (2007) published the work “Indices de phytotoxicidad en residualos orgánicos during composting”, in Revista de la Ciencia del Suelo y Nutrición Vegetal. The authors concluded that the description of the phytotoxic potential of the compost organic matter, during the maturation phase, is established with greater sensitivity in the radish bioassays, compared to the lettuce tests, as well as the feasibility in the elaboration of specialized substrates for use agricultural.

Costa et al. (2009) published the work “Composting of solid waste from refrigerators”, in the Revista Brasileira de Engenharia Agrícola e Ambiental. The authors found that composting is an efficient system in the treatment of solid waste from slaughterhouses and small slaughterhouses, demonstrating that after 90 days of composting, nutrients are recycled from the waste.

Silva et al. (2009) published the work “Microbial diversity in a bagasse-based compost prepared for the production of *Agaricus brasiliensis*”, in the Brazilian Journal of Microbiology. It was observed that the compost based on sugarcane bagasse and coast-cross straw supported a diverse microbial population, mainly *Bacillus* spp, *Streptomyces* and *Aspergillus fumigatus*, which are responsible for fiber degradation and physical and chemical characteristics of the final compound. In this sense, it was seen that solid agro-industrial residues have great potential for the formation of low-cost organic compounds.

Primo et al. (2010) published the work "Evaluation of the nutritional quality of organic compost produced with tobacco residues", in the Revista Brasileira de Engenharia Agrícola e Ambiental. Their results showed that the composting of bovine manure and crushed tobacco stalks resulted in a higher concentration of macro and micronutrients, the occurrence of the elimination of nicotine present in the tobacco and the absence of pesticides in the organic compost, presenting quality for agricultural purposes.

Carneiro et al. (2013) published the work "Nutrient loss in composting of agroindustrial residues", in the Revista Engenharia Agrícola. The authors observed that the double washing of the compost furrows in the first month and a single washing in the second allows the smallest reduction of nitrogen in the produced composts. It was also verified that the coverage of the compost yard reduces the losses of K, Mg, Na and N, in addition to the fact that the compounds produced were of high quality and agronomic value, and can be used as organic fertilizers.

Costa et al. (2016) published the paper "Composting time reduction of agro-industrial wastes" in the Revista Engenharia Agrícola. The authors analyzed uncovered windrows and observed a shorter composting time and significant volume reduction. However, there is loss of nutrients by leaching.

Santos et al. (2016) published the work "Growth analysis of potted gerbera conducted with mineral fertilization and organic fertigation", in Revista Ciencia e Investigación Agraria. It was found that plants grown with organic compost had a higher growth rate. On the other hand, plants cultivated with chemical fertilization had higher net assimilation, indicating greater efficiency of dry matter conversion.

Bernardi et al. (2018) published the work "Microbiological activity during the composting of wastes from broiler productive chain", in the Revista Engenharia Agrícola. It was verified that the amount of carbon present in the chicken waste influenced the microbiota of the process. It was also observed that the enzymatic activity was higher in the thermophilic phase of the composting process.

Coelho et al. (2018) published the work "Control of *Sclerotinia homoeocarpa* in turf with organic compounds", in the Revista de Ciências Agrárias. The authors concluded that the composting of the agro-industrial residues described allowed the production of two organic compounds with good agronomic quality, from which fungi capable of suppressing the growth of *S. homoeocarpa* were isolated.

Méndez-Matías et al. (2018) published the work "Composting of agro-industrial residues inoculated with lignocellulosic fungi and modification of the C/N relationship", in the Revista Mexicana de Ciências Agrícolas. It was demonstrated that maguey mezcal bagasse added to bovine manure and inoculated with any of the two fungi reached C/N values that value it as mature compost from the 103rd day of composting.

Gaspar et al. (2020) published the work "Economic-financial analysis of the management of organic solid waste in an agro-industry of minimal vegetable processing", in the Revista Engenharia Sanitária e Ambiental. The authors found that solid waste management in agro-industries minimizes socio-environmental impacts and final disposal costs.

Marcon et al. (2020) published the work "Viability of using organic substrates according to toxicity tests and the antioxidant activities of tomato seeds and seedlings", in the International Journal of Agriculture and Natural Resources. It was seen that extracts derived from tree pruning and sawdust had the greatest positive effects on seed germination, while cotton derivatives and sugarcane residues had a negative effect, indicating a certain toxicity.

Debernardi-Vázquez et al. (2020) published the work "Composting of byproducts from the orange (*Citrus sinensis* (L.) Osbeck) and sugarcane (*Saccharum* spp. hybrids) agroindustries'', in Revista Ingeniería e Investigación. The authors observed that the composting of agro-industrial residues is viable and that the organic compounds (bifertilizer) obtained from composting can be used to correct the soil according to the characteristics of pH, C/N ratio, organic matter, carbon and macro and micro nutrients present.

CONCLUSION

Scientific prospecting found a greater concentration of research on agro-industrial waste composting in the years 2018 and 2020, with emphasis on Brazil as the main country of research execution institutions. The thematic area "Agrarian Sciences" and the periodical "Engenharia Agrícola" have the highest number of publications in their respective classes. The main stages of composting technology were gross waste, screening, grinding, homogenization, composting, screening, storage and use. The relevance of controlling the humidity, aeration, temperature, pH, carbon and nitrogen ratio (C:N) and particle size was verified. Therefore, composting is a potential technology for transforming agro-industrial waste into organic fertilizer.

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