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CROP PRODUCTION

Compounds identified in plant extracts applied to agriculture and seed treatment

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ABSTRACT: Plant extracts effects have been regarded and proven in researches under different applications in agriculture, including seed treatment. The plant extracts effectiveness is attributed to the presence of certain classes of compounds; therefore, studies that aim to identify and quantify these composites, which are present in plant extracts used in agriculture, are important, as well as the seed treatment. This research aimed to understand and describe through a systematic review, what were the main carried approaches, classes and identified compounds in studies with plant extracts to different applications in agriculture and the seed treatment. The period 2015 to 2020 was the one that exposed the higher research publication indexes, considering the theme under analysis, plant extracts in agriculture, seeking to identify or quantify the presence of metabolic composites, indicating a growing interest in this theme. Such studies pursued identifying and/or quantifying the compounds that are present in the plant extracts. The phenolic compounds constitute the priority class of metabolites to different functions, effects and applications in agriculture, mainly in seed treatment. The terpenes present a substantial potential as bioinsecticides to agriculture. Plant species that are rich in phenolic and terpenes compounds are a significant source of alternative control in the protection of the productive system.
Key words: secondary metabolites, terpenes, seed treatment, alternative control.

Compostos identificados em extratos vegetais aplicados na agricultura e no tratamento de sementes

RESUMO: Efeitos de extratos vegetais têm sido apontados e comprovados em pesquisas sob diferentes aplicações na agricultura, incluindo o tratamento de sementes. A eficácia de extratos vegetais é atribuída a presença de certas classes de compostos, logo, sendo importante estudos que visam a identificação e quantificação destes compostos presentes em extratos de plantas usados na agricultura, bem como para o tratamento de sementes. Objetivou-se compreender e descrever, por meio de uma revisão sistematizada, quais as principais abordagens realizadas, classes e compostos identificados em estudos com extratos vegetais para diferentes aplicações na agricultura e no tratamento de sementes. O período 2015 a 2020 foi o que apresentou os maiores índices de publicações de pesquisas que exploram extratos vegetais na agricultura, buscando identificar e, ou quantificar os compostos presentes nos extratos vegetais. Os compostos fenólicos constituem a classe prioritária de metabólitos para diferentes funções, efeitos e aplicações na agricultura, principalmente no tratamento de sementes. Os terpenos apresentam grande potencial como bioinseticidas para a agricultura. Espécies de plantas ricas em compostos fenólicos e terpenos são fontes potenciais para controle alternativo na proteção de sistemas produtivos.
Palavras-chave: metabólitos secundários, terpenos, tratamento de sementes, controle alternativo.

INTRODUCTION

Plant compounds provide multiple potentialities, regarding their employment in agriculture, including the seed treatment (ARSHAD et al., 2019; AL-MOHMADI; AL-ANI, 2019). Some studies have regarded the plant extract effect as resistance inducers (COSTA et al., 2019), growth promoters in plants or biostimulating effect (COZZOLINO et al., 2020), herbicidal effect (ZAKA et al., 2019; FINDURA et al., 2020), nematicidal effect (MÜLLER et al., 2016; COLTRO-RONCATO et al., 2016), insecticidal effect (PAVELA et al., 2018) and, mainly, phytopathogenic organisms control effect (MEENA et al., 2020; NCISE et al., 2020).

The effectiveness of plant extracts employed in agriculture to different purposes, particularly in the seed treatment, is found by the presence of some classes of majoritarian metabolites composites, such as phenolic compounds, terpenes, fatty acids and nitrogen compounds, which function in the most varied roles (MANGWENDE et al., 2019; CHANDEL & KUMAR, 2017, ZIDA et al., 2018).

Considering the previous description, some studies tried isolating, characterizing, and understanding the method and action of these

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compounds (HAMAD et al., 2019; ANDRIANA et al., 2018; AFTAB et al., 2019; AHMED et al., 2019; DIKHOBA et al., 2019; COZZOLINO et al., 2020; PHAMBALA et al. 2020, ANIYA et al., 2020). However, there are only a few researches regarding plant extracts that try supporting its results from its chemical characterization and isolation of the active compounds, once the investigations are restricted to available information on literature or even qualitatives/colorimetric tests to identify only the presence or absence of such composites.

In the last few years, a growing interest in the application of plant extracts as an alternative to the agrochemicals employment at cropping systems has become a reality (CARMELLO & CARDOSO, 2018; JANG & KUK, 2020; JANG & KUK, 2019; THUERIG et al., 2018; NARASIMHAMURTHY et al., 2019), hence, studies that aim the characterization of the existing compounds in plant extracts used in agriculture, including seed treatment.

Exploring the natural occurrence of metabolites can supply a safer and low-cost alternative to the farmers, promoting the local sustainable use of biological resources (NCISE; DANIELS; NCHU, 2020). For this purpose, it is necessary to understand, from the already concluded pieces of research, the incidence or not, as well as the identification and quantification, of majoritarian classes of metabolites active in species and genders of studied plants for different uses in agriculture, aiming different effects, resulting in useful information to the planning and execution of future research, oriented to the plant compounds employment.

Based on the above consideration, this research had as an objective the understanding and describing, through a systematic review, the main approaches, classes and compounds identified in studies with plant extracts under different applications in agriculture and in seed treatment.

DEVELOPMENT

In order to execute and constitute the range of this systematized review, some scientific papers, indexed to the *Web of Science* database, were selected. The decision of choosing this repertoire can be justified by its global database of indexation of papers linked to periodicals of great international visibility.

To provide a better search terms definition, a previous investigation was made, through different strategies based on Boolean operators, by means of basic research, with a temporal cut from January of 2010 to December of 2020. After the analysis of this research and evaluating the papers that were aligned to the thematic review, the following key-terms set was defined: "plant* extract*" and agriculture; "plant* extract*" and "seed* treatment*"; "plant* extract* and "alternative control"; "plant* extract*" and "seed germination" and "plant* extract*" and seed fungi. It was defined, as criteria of inclusion, only studies directly applied and related to the employment of plant extracts in agriculture. Consequently, review papers and the ones related to the zootechny, medicine, fishing engineering, veterinarian fields and researches that were not related to the matter in question were not selected.

In this way, 298 scientific articles were selected, because they approached and were references to the study theme of this review. The papers in this amount were evaluated again, and the duplicated ones were excluded, numbering 219 studies in the range of the systematic review, which were identified in relation to the publication year and the concluded approach regarding its identification and quantification of the compounds present in the extracts. In relation to the approach, the scientific papers were classified into the ones that identified the compounds, the ones that only determined their classes, which made inferences based on literature, or the ones that did not mention, at any moment, the extract composition.

Posteriorly, considering the scientific articles that somehow approached the composition of the plant extracts, which were also analyzed, and the main compounds were classified into five categories of metabolites, according to TAIZ & ZAIGER (2013), which are: 1. Phenolic Compounds; 2. Terpenes; 3. Fatty Acids; 4. Nitrogen Compounds and 5. Other.

It was tried to relate the metabolites categories with the different applications in agriculture, which are: (A) Insects: control related to pests/effects on biology insects/repellency to insects; (B) Phytopathogenic organisms: diseases control/effects on fungi/bacteria/nematode biology (in vitro/in vivo/both); (C) Herbicide effect: allelophatic effect/plant control; (D) Resistance induction: resistance to insects/pathogens/abiotic factors; (E) Biostimulating effect: biostimullating effect/production.

The papers that approached the plant extracts with employment in agriculture and seed treatment to the point of identifying the majoritarian compounds were individually analyzed in a Table to generate pertinent data about each one of the most relevant compounds and the plants in which they were identified.

A quali-quantitative analysis of the selected scientific papers was made, using the bibliometric indicators, with the distinction of the following items: publication year, realized approach regarding the determination or identification of the active composites in plant extracts, effects on agriculture, identified compounds, plant species/gender and reference. The data were submitted to analysis and Tables and graphs were elaborated.

Regarding the realized approach about the composition of the plant extract, considering the 219 analyzed studies, 47,94% of them made inferences related to the composition of the extracts only on literature database, 12,78% of them determined the presence of some class of compound, 15,52% of them were investigations that identified metabolites, and 23,74% of them did not mention the composition of the extract, and there was a greater expressiveness on the number of publications between the years of 2015 and 2020 (Figure 1) for all the cases.

From the data set of researches that explored the potentialities of plant extracts for different applications in agriculture and seed treatment (CASER et al., 2020; KARABUYUK & AYSAN, 2019), it was noticed that a great amount of them conducted their results from the inferences to available pieces of information on literature, or even there is no mention at all to any metabolite (MAMARABADI et al., 2018) that compose the plant extract. This demonstrated that scientific literature still lacks deeper investigations about the classes of compounds and their chemical constituent present in the plant extracts, as well as their effects in the proposed applications.

Besides the expressive number of publications that made inferences of their results only in literature data or that did not even mention the compounds, it is noticeable the interest and demand of Science, in the last years, for studies that search for identification and isolation of substances present in plant extracts, with a higher proportion to these approaches in the period of 2015 to 2020 (Figure 1) (ANDRIANA et al., 2018; AFTAB et al., 2019; ANIYA et al., 2020).

It must be highlighted the importance of the identification and the isolation of substances, such as secondary metabolites, originated from plant extracts, to assist in the understanding of the action mechanisms and the functions of these compounds. It is suggested, as a possible justification for a greater quantity of studies with an approach focused on inferences to literature, the complexity and difficulty on the isolation of the active principles, the limitation on equipment mastery, reagents, methodologies or even the operational cost on the part of the pieces of research (AFTAB et al., 2019).

One of the main methods employed to characterize and identify substances, in special the ones that compose the plant extracts is a methodology

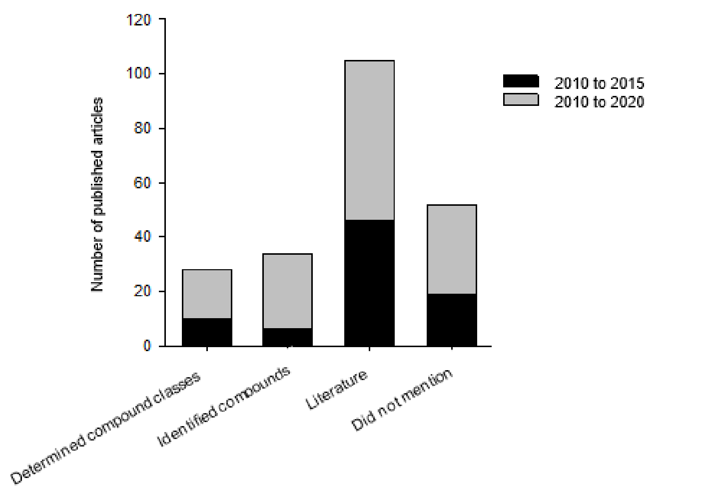

Figure 1 - Number of published and indexed articles in *Web of Science* about the employment of plant extracts in agriculture and application of seed between January of 2010 and December of 2020, inside each approach realized regarding the composition of such plant extracts.

called gas chromatography coupled to mass spectrometry (GCMS) and high-performance liquid chromatography (HPLC) (LAKSHMEESHA et al., 2019, AFTAB et al., 2019). Besides, colorimetric methods, such as *Folin-Ciocalteu*, are employed to quantification of phenolic compounds, among other substances (SWAIN, HILLIS, 1959).

AFTAB et al. (2019) evaluated the antifungal activity of different concentrations of *Nigella sativa* L. extracts, prepared with maceration in methanol and identified that, to the concentration of 50 mg/mL^{-1}, there was a reduction from 86% to 88% of the *Fusarium oxysporum* and *Macrophomina phaseolina* fungal biomasses. The authors evaluated the phytochemical profile of the extract through the GCMS analysis and detected the presence of Octadecadienoic acid, Pentadecylic acid, 1,2,3,4-Butaneteterol, Octadecanoic acid and Linoleic acid with greater predominance in the extract, suggesting these as the possible responsible chemicals for the *N. sativa* L antifungal activity.

From the total of 167 publications with plant extracts that attributed their effects to some compound, in other words, from the ones that were based on literature, determined classes or identified substances, 62,24% from them related the presence of the phenolic compounds, 28,74% of them identified terpenes, 17,96% of them identified fatty acids, 17,96% of them stated nitrogen compounds and 20,95% of them related other compounds (Figure 2).

Plants produce countless and different groups of substances, which do not present restricted functions in the growth processes and plant development, being; therefore, classified as secondary metabolites (TAIZ & ZEIGER, 2013).

Among these, a great variety of compounds presented, as a basic structure, a Phenol group, a functional hydroxyl group and an aromatic ring, substances that are known as phenolic compounds (TAIZ & ZEIGER, 2013). The phenolic compounds presented approximately 10.000 compounds that were chemically distinct, among them some soluble in organic solvents, others are carboxylic acids, glycosides and a huge group of insoluble polymers (RAMOS et al., 2019).

Linked to their chemical diversity, the phenolic compounds have multiple functions in plants, as a defence against herbivores, pathogens, mechanical support, pollinator’s attractiveness, ultraviolet protection, as well as the fact that they perform as vegetable growth regulators and natural herbicides, such as ß-sitosterol, quercetin, caffeic acid, gallic acid, among others (FERRAZ et al., 2017; KARABUYUK & AYSAN, 2019).

The terpenes constitute a bigger group of plant metabolites, insoluble in water and synthesized from acetyl-CoA or from glycolytic, considering that all of their constituents are derived from the union of pentacarbonated unities with isopentane ramifications (TAIZ & ZEIGER, 2013). As the phenolic compounds, they also act in the growth promotion, defence against herbivores and pathogens, besides being considered an important source of substances that act against plant intoxication, such as terpene lactones, azadirachtin e gibberellins (DIKHOBA et al., 2019; AHMED et al., 2019).

Through the synthesis of one acetyl-CoA molecule with one of malonyl-CoA, after some reactive processes, it happens the formation of fatty acids with carbon chains of 16 to 18 atoms. Fatty acids are related to the synthesis of lipids, such as glycolipids, triacylglycerols or the ones that form cuticles in the plants, executing important functions, such as insecticides, mainly, as fungicides, as examples of palmitic acid, oleic acid, linoleic acid, stearic acid, arachidonic (VAZQUEZ-COVARRUBIAS et al., 2015; AHMED et al., 2019; TEMBO et al., 2018).

Among the frequently identified composites in plants, the nitrogen compounds are found, being substances that have nitrogen in its chemical structure, such as alkaloids and glycosides, and are important in the prevention against the herbivores attack, through the volatile toxins liberation, such as nicotine, hydrocyanic acid and isothiocyanate (TAIZ & ZEIGER, 2013; KARABUYUK & AYSAN, 2019).

Besides the phenolic compounds, terpenes, fatty acids and nitrogen compounds, the plants produce many other substances, such as Phyto-vitamins, and sugars responsible for different functions (EZEONU et al., 2018; POTRICH et al., 2020).

Many pieces of research have proven that these secondary metabolites, derived from plant extracts, display action against predators and phytopathogenic organisms, based on their toxicity and capacity of repelling herbivores and microorganisms when tested in vitro and in vivo (COSTA et al., 2019; COZZOLINO et al., 2020; FINDURA et al., 2020; PAVELA et al., 2018; MEENA et al., 2020; NCISE et al., 2020). Furthermore, they act in the resistance induction, the building of polymers barriers, synthesis of enzymes related to defence mechanisms, growth promotion, herbicides, insecticides and the degradation of the cell wall of phytopathogenic organisms (ANZLOVAR et al., 2020; ROMERO-BASTIDAS et al., 2020).

Therefore, studies with secondary metabolites allow the identification of different practical applications of plant extracts in agriculture and seed treatment, due

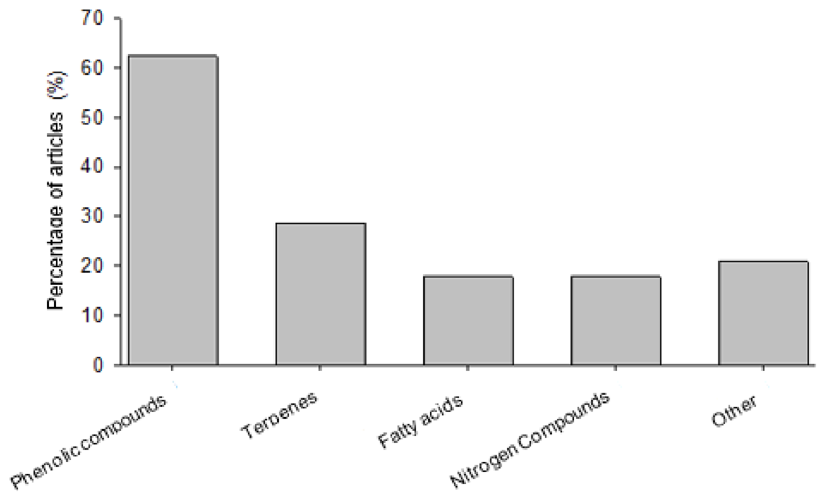

Figure 2 - Percentage of indexed articles in *Web of Science*, in the years of 2010 to 2020, for each class of active composites in plant extracts, from studies that attributed their results to the presence of some compound. Idem 1.

to their effects and mode of action (COZZOLINO et al., 2020; PHAMBALA et al., 2020; NCISE et al.,2020; MANGWENDE et al., 2019; AFTAB et al., 2019; ANIYA et al., 2020; ALVAREZ-PEREZ et al., 2020).

Considering the different applications of plant extracts in agriculture, from the total of 167 publications that have highlighted metabolites, 96 of them were linked to the application with effect in phytopathogenic organisms and the correlation of different classes of compounds; 62,5% phenolic compounds, 29,16% terpenes, 21,87% fatty acids and 19,79% nitrogen compounds (Figure 3A).

Some substances, such as antioxidative enzymes, specially peroxidase, polyphenol oxidase and phenylalanine ammonia-lyase, have a great capacity of controlling phytopathogenic organisms, such as bacteria, fungi and nematodes, because they are directly involved with the plant's defensive system (SOUZA et al., 2015).

Conversely, 32 scientific papers that approached application to effects on insects, 56,25% attributed their effects to phenolic compounds, 50% to terpenes and 25% to nitrogen compounds (Figure 3B). Many pieces of research have proven several functional roles of terpenoids in agriculture, as well as seed treatment, considering that these are among the main bioactive composites that were highlighted with insecticide action (BALDIN et al., 2015). The terpenes group presented many volatile allelochemical substances, such as limonene, menthol, phytol, linalool, 1,8-cineole, and azadirachtin, which have been utilized as repellents, in many cases preventing and reducing the contact between plant-insect and, this way, avoiding some damages to the productive system (ARSHAD et al., 2019, NISSINEN et al., 2020).

GARCIA et al. (2019) evaluated the exposure of larvae, pupae and adults of *Ceraeochrysa claveri* to *Azadirachta indica* oil, high in azadirachtin, an important terpenoid. The authors identified that in the concentrations 0,5%, 1% and 2%, there was stress and death cell, besides promoting delay on the spermatogenesis of insects that were submitted to the treatment, proving how important it is the employment of natural extracts, rich in terpenes, as bioinsecticides for the agroecosystem handling.

Positive results were also reported by ARSHAD et al. (2019) in evaluating the effects of *Azadirachta indica* A. Juss and *Melia azedarach* L. extracts to control pest insects in cotton plants (*Dysdercus koenigii* Walk, *Aphis gossypii* Glover and *Amrasca devastans* Distan), showing an average of 65,4% and 58,8% of controlling for both extracts, respectively.

Concerning the application with the effect of resistance induction, from the total of 10 scientific papers that approached this theme, 60% of them reported phenolic compounds and 20% fatty acids (Figura 3C). From the 19 that studied the biostimulation effect and growth promotion, 78,95% of them highlighted phenolic substances, 21,05% nitrogen compounds, and 15,78% terpenoids (Figure 3D).

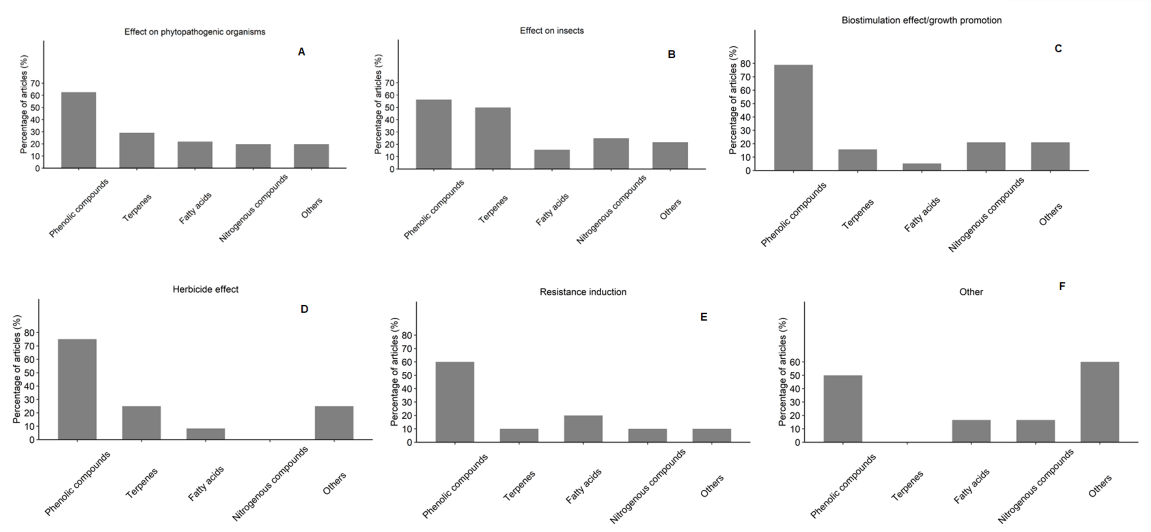

Figure 3 - Overview of the 167 publications that attributed their effects to metabolites, connecting the different applications in agriculture with the categories of compounds approached in the review published on *Web of Science* between the years 2010 and 2020. Percentage of articles that approached (A) the effect on phytopathogenic organisms to the different classes of compounds; (B) the effect on insects to the different classes of compounds; (C) the resistance induction in insects to the different classes of compounds; (D) biostimulation effect /growth promotion to the different classes of compounds; (E) herbicide effect to the different classes of compounds and (F) other effects to the different classes of compounds.

In relation to the application with herbicide effect, from the 12 publications that dealt with the matter, 75% of them presented a relationship with phenolic compounds, 25% with terpenes and 25% with other compounds (Figure 3E). Other plant extract applications, such as retrieval and handling of soils presented 6 publications, 50% of them highlighted phenolic compounds (Figure 3F).

When the classes of compounds are correlated to the different application approaches and plant extract effects in agriculture and seed treatment, there was a greater focus on phenolic compounds with predominance to all applications. Besides, the terpenes can be enhanced as an important class of metabolites in controlling insects.

Phenolic compounds, due to their substance heterogeneity, stand out as a class of metabolites that are gathered to the secondary metabolism of plants. For this reason, they present numberless functions, such as herbicides, biostimulation, insecticides, resistance inductors, and, mainly, fungicide (NISSINEN et al., 2020; ANIYA et al., 2020; LAKSHMEESHA et al., 2019).

Terpenes have been reported in the literature as important mechanisms to insect control, being the base to many industrial insecticides, due to their low persistence in the environment and low toxicity to mammals (TAHA-SALAIME et al., 2020; RODRÍGUEZ-MONTERO et al., 2020). A great part of plants produce substances arising from the mixture of volatile monoterpenes and sesquiterpenes called essential oils, being toxic to the majority of insects (ARSHAD et al., 2019).

An important piece of data about the protective function of volatile terpenes is a certain mechanism, in some plant species, such as cotton, tobacco, among others, that only releases these compounds after the insect starts the plant intake (PEREIRA et al., 2020; TAHA-SALAIME et al., 2020).

Considering only the pieces of research that identified the active substances in the plant extracts, some plant species stand out, such as *Syzygium aromaticum*, *Curcuma longa* L, *Allium sativum* L and *Ocimum basilicum* (Table 1 and Table 2).

HAMAD et al. (2019) evaluated the fungicide action in extracts of *Syzygium aromaticum, Tectona grandis, Ocimum basilicum* and *Eucalyptus gomphocephala* in three phytopathogenic fungi, *Fusarium oxysporum*, *Rhizoctonia solani* and *Alternaria solani,* and the insecticide action against *Culex pipiens* larvae. The authors observed positive results of all extracts and, through GCMS analysis, identified that, for the extract of *T. grandis*, the most abundant compound was oxalate of cyclohexyl-Pentium (8,7%), for the extract of *E. gomphocephala,*

Table 1 - Main isolated compounds in the analyzed studies with plant extracts and their effects on employment in agriculture.

Main described compounds	Effect in agriculture	Species/Gender of the plant	Reference
p-Cymene, estragole, furfural, α-linolenic acid, 1βH-romneina, eugenol acetate, ethylguaiacol, cyclohexylpentil oxalate, -4,4-dimethyl-2-pentene.	Phytopathogenic organisms	*Ocimum basilicum, Eucalyptus gomphocephalawith, Syzygium aromaticum, Euphorbia paralias*	HAMAD et al., 2019.
Guaiacol, benzene acetic acid, phenol, benzene acetic acid methyl ester, methyl salicylate, ácido vanílico, syringol, vanillic acid methyl ester and benzoic acid.	Herbicide effect	Tridax procumbens L	ANDRIANA et al., 2018.
Octadecadienoic acid, O-Pentadecylic acid, 1,2,3,4, butaneteterol, octadenoic acid and linoleic acid.	Phytopathogenic organisms	*Nigella sativa* L.	AFTAB et al., 2019.
Triterpenóides, ß-amyrin, a-amyrin, neophytadiene (4,38%) and palmitic acid.	Phytopathogenic organisms	*Curtisia dentata; Markhamia obtusifolia*	DIKHOBA et al., 2019.
Eugenol, β-caryophillene, acetyl eugenol.	Phytopathogenic organisms	*Syzygium aromaticum*	LAKSHMEESHA et al., 2019.
Lauric acid, myristic acid, palmitic acid, ricinoleic acid, stearic acid, oleic acid, palmitic acid ethyl ester, 13-hexyloxacyclotridec-10-en-2-ona.	Other	*Cocos nucifera; Carapa guianensis*	BATAGLION et al., 2014.
Bio-Aromatic heterocycles, caffeic acid, vanillin, rutin, luteolin, diosmetin, p-coumaric acid, vanillic acid, apigenin-7-glucoside, diosmetin-7-glucoside, eluteolin-7-glucoside, miconazole, ketoconazole e clotrimazole, chlorogenic acid, gallic acid, luteolin-7-glucoside, ferulic acid, neochlorogenic acid, quercetin and dihydroquercetin.	Phytopathogenic organisms	*Lepidium sativum; Punica granatum*	TAYEL et al., 2016.
Phenolic, polyphenol, alkaloids, terpenoids, polypeptide, cardiac glycosides, reductive compounds and anthraquinones	Phytopathogenic organisms	*Garcinia kola*;*Tetrapleura tetraptera*	UMANA et al., 2016.
Magnolo, honokiol.	Phytopathogenic organisms	*Magnolia officinalis* Rehder e Wilson	THUERIG et al., 2018.
Furfural; 2-furanmethanol; benzyl alcohol; phenethyl alcohol.	Other	*Nandina domestica* Thunb.	HU et al., 2018.
Shikimic acid.	Herbicide effect	*Illicium verum* Hook. f.	ANIYA et al., 2020.
Sesquiterpene ketolactone, curcumin.	Phytopathogenic organisms	*Curcuma zedoaria*	HAN et al., 2018.

it was p-cymene (28,8%), the extract of *O. basilicum* contained estragole (65,9%), 3-alilguaiacol (65,8%) and acetate of eugenol (46,6%) for the extract and the essential oil of *S. aromaticum,* pointing out that all the extracts can be utilized as natural biofungicides and insecticides.

LAKSHMEESHA et al. (2019) determined the action of nanoparticles of zinc oxide and *Syzygium aromaticum* extract, in controlling growth and production of mycotoxins of *Fusarium graminearum* and identified, through GCMS, elevated levels of eugenol, β-caryophyllene, and acetyl eugenol. The authors revealed that the application of the nanoparticles promoted a decrease in the ergosterol content and caused damages to the membrane integrity of the fungi.

In accordance with the first indicated results in this review, it was observed that, among the main classes of compounds identified in the pieces of research, the phenolic compounds and terpenes stand out as the prevailing categories among the identified substances, considering the application to control phytopathogenic organisms, and insects, herbicide effect and resistance induction as central themes of the studies.

The maintenance of the seeds' sanitary quality, as well as the involved processes in their treatment, have been under the spotlight because it is one of the main spreading pathways of plant species (ANŽLOVAR et al, 2020). The fungi, insects, viruses and bacteria are among the organisms that influence directly the sprouting process, establishment in the field and storage of grains and seeds (SNEHA et al., 2020).

Table 2 - Main isolated compounds in the analyzed studies with plant extracts and their effects on employment in agriculture.

Main described compounds	Effect in agriculture	*Species/Gender of the plant*	Reference
3-O-caffeoyl Acid, 4-O-Feruloylquinic; nicotiflorin (Kaempherol-3-O-Rhamnoglucoside); Q-3-O-glucoside; rutin (Quercetin-3-O-Rhamnoglucoside; 5-O-Feruloylquinic acid; 3-O-Feruloylquinic acid; 5-O-p-Coumaroylquinic acid; 4-O-caffeoyl oil, 5-O-Feruloylquinic; 4-O-caffeoylquinic; 3-O-caffeoylquinic; chlorogenic acid (5-O- caffeoylquinic acid);	Phytopathogenic organisms	*Licium europaeum*	TEJ et al., 2018.
(+) - (S) -ar-turmerone.	Phytopathogenic organisms	*Curcuma longa* L.	FU et al., 2018.
Allyl isothiocyanate.	Phytopathogenic organisms	*Crambe abyssinica*	COLTRO-RONCATO et al., 2016.
Quinine Acid; chlorogenic acid; Quercetin-glucuronide; Hispidulin; Tagitinin; O-methyl titoni; Tirotundin 3-O	Insects	*Tithonia diversifolia*	PAVELA et al., 2018.
3-hydroxy-12-olean-28-oic acid (oleanolic acid).	Phytopathogenic organisms	*Melianthus comosus*	ELOFF; ANGEH; MCGAW, 2017.
Cinnamic acid and flavone compounds, p-hydroxybenzoic acid and vanillic acid.	Resistance Induction	*Solanum tuberosum*	MOUSHIB et al., 2013.
Salicylic-Phenylpropanoid Acid.	Resistance Induction	*Anacardium occidentale* Linn; *Zingiber officinale* Rosc	ANDAYANIE et al., 2019.
Nicotina; β- Caryophyllene; lupeol.	Insects	*Nicotiana tabacum* L.; *Anadenanthera colubrina* Vell; *Agave americana* L.	PEREIRA et al., 2020.
Luteolin 7-rutinoside, Apigenin-6-C-glucosyl-8-C-arabinoside.	Phytopathogenic organisms	*Flourensia cernua*	ALVAREZ-PEREZ et al., 2020.
n-feruloyl putrescine, Tryptophan, chlorogenic acid, Isoquercitrin, α-solanine, α-chaconine,	Phytopathogenic organisms	*Solanum tuberosum*. L	PANE et al., 2020.
20-hydroxyecdysone, makisterone A and ciosterone.	Insects	*Ajuga iva*	TAHA-SALAIME et al., 2020.
Saponins.	Other	*Quillaja saponária*	ADOMAITI et al., 2020.
Isopropanol: Dichloromethane.	Insects	*Lippia graveolens, Ruta graveolens, Enterolobium cyclocarpum, Adonidia merrillii, Zingiber officinale*	RODRÍGUEZ-MONTERO et al., 2020.

Although, the main form of control still is based on the treatment with agrochemical products, the employment of these substances has been questioned, due to adverse impacts, such as the emergence of resistant species, residue of great persistence in the environment and damage to other organisms. In this context, alternatives to the seed treatment have been suggested and researched, among them, there is the employment of plant extracts (GHIMIRE et al., 2020; ALSAHLI et al., 2018).

Of the studies that identified substances present in plant extracts to the application on seeds, it was noticed that *Allium sativum* L. had a great relevance among the pieces of research (Table 3). Mangawende et al. (2019) evaluated the effects of *Allium sativum* L., *Carica papaya* L., *Datura stramonium* L., *Lantana câmara* L., *Tagetes minuta* L and *Zingiber officinale* Roscoe *in vitro* and *in vivo* extracts on the seed treatment of *Coriandrum sativum* L against *Alternaria alternata* (PPRI 18133) and identified that *A. sativum* L and *Z. officinale* R. presented similar effects, which are comparable to the synthetic fungicide Celest® XL. The fungicide effects of both extracts were attributed to some metabolites, such as dialil tio sulfinate and S-alil-L-cysteine sulfoxide.

ANŽLOVAR et al. (2020) evaluated extracts and the essential oil of *Solidago virgaurea*

Table 3 - Main isolated compounds in studies with plant extracts and their effects in the seed treatment.

Main described compounds	Effect in agriculture	Species/Gender of the plant	Reference
Tetradecanoic acid, Pentadecanoic acid, hexadecanoic acid, phytol, linalool, 1,8-cineol and 9, 12, 15-octadecanoic acid.	Phytopathogenic organisms	*Chrysanthemum frutescens*; *Thespesia populnea* var. Acutiloba	DERBALAH et al., 2012.
Sulfoxide of (+)-S-allyl-L-cysteine, thiosulfinate, 5,6-dihydro-6-pentyl-2H-pentyl-2-H-pyran-2.	Phytopathogenic organisms	*Allium sativum; Zingiber officinale*	MANGWENDE; et al., 2019.
Astilbin.	Insects	*Tithonia diversifolia; Psychotria prunifolia*	TAVARES et al., 2014.
Butane, 1,1-diethoxy-2-methyl-; 4-Hydroxy-3-methylacetophenone; 3,7,11,15-Tetramethyl-2-hexadecen-1-ol; 2-decen-1-ol; 1-tridecene; Tridecanoic acid, Methyl ester; n-Hexadecanoic acid; Hexadecanoic acid, Ethyl ester; Phytol; 9,12-Octadecadienoic acid (Z,Z); 9,12,15-Octadecatrienoic acid, Methyl ester (Z, Z, Z); 4-tridecene, (Z); Phthalic acid, 2-methoxyethyl tetradecyl ester; 2-hexanone, 5-methyl, Z-2-dodecenol, Nonanoic acid; Oxalic acid, Dodecyl 2-methylphenyl ester; Methyl methane sulfate; Propane, 1,1-diethoxy-; 1-desoxi-d-altritol; 2-Mercaptothiazole.	Phytopathogenic organisms	*Allium sativum* L	MUTHUKUMAR et al., 2010.
ß-Phellandrene; Cycloheptasiloxane tetradecamethyl; Diethylcarbonyl-dicarbonyl-cyclic-diether; 1,4-tetra-cosamethyl-cyclic-dioxide; Tetratetracontane; Hexadecanoic acid methyl ester; Cyclononosiloxane octadecanmethyl; 6-Dodecatrien-3-ol, 3,7,11-trimethyl; Caryophyllene; 9-Octadecenoic acid *(z);* 2,6-Octadien-1-ol; 3,7 dimethyl acetate; Butanoic acid; α-Terpineol acetate; MYO-INOSITOL; 1,8 cineole; lyanol; 3-Cyclohexen-1-ol, 4-methyl-1-(1-methylethyl); 3-cyclohexene-1-methanol, α-4-trimethyl-p-menth, 1-en-8-ol.	Insects	*Cassia senna*	DERBALAH, 2012.
Curcumin, camphor, turmerone.	Resistance Induction	*Curcuma longa* L.	ALSAHLI et al., 2018.
Orientine, Luteolin, Veratric acid, Chlorogenic acid, Protocatechuic acid, p-Coumaric and Ferulic acid.	Herbicide effect	*Miscanthus sacchariflorus*	GHIMIRE et al., 2020.
AgNPs	Other/herbicide effect	*Ficus racemosa*	SNEHA et al., 2020.
α-Pinene, Humulene epoxide II	Phytopathogenic organisms	*Solidago* spp.; *Fallopia japônica*	ANŽLOVAR et al., 2020; JANEŠ; DOLENC, 2020

L., *Solidago canadensis* L and *Solidago gigantea* Aiton and *Fallopia japonica* against fungi associated with wheat seeds, such as *Alternaria alternata, Alternaria infectoria, Aspergillus flavus, Epicoccum nigrum* and *Fusarium poae*. The authors determined that the extracts of *S. canadensis* promoted 61,8% of inhibition, 47,1% to *S. gigantea* and 56,9% to *S. virgaurea*, against *F. poae*. The evaluation of the extracts of the *Solidago* spp. species, through GCMS, demonstrated that among their main chemical constituents, the terpenes are present, mostly the α-pinene, germacrene D and the bornyl-acetate.

SNEHA et al. (2020) synthesized silver nanoparticles (AgNPs), which contained extracts of different plant parts of *Ficus racemosa*, in order to determine the antifungal activity against *Bacillus subtilis* and *Staphylococcus equorum*, and in the sprouting of *Triticum aestivum* L seeds. The authors confirmed the AgNPs antibacterial activity and the effect on the sprouting of wheat seeds, which demonstrates the potentiality of the employment of plant extracts under different optics for application.

GHIMIRE et al. (2020) evaluated the allelopathic potential on the extracts of *Miscanthus sacchariflorus* on the concentrations of 100, 1000 and 10000 ppm in the sprouting, plant growth, biomass and biochemical parameters of weeds (*Chenopodium album, Bidens frondosa, Amaranthus viridis, Artemisia princepsvar. Orientalis, Commelina communis, Oenothera biennis Erigeronōnensis, Digitaria ciliares* and *Echinochloa cromo*). The employment of leaves' extracts of *M. sacchariflorus* suppressed 100% of the sprouting of weed seeds, reduced the root length, aerial part, the mass of the fresh material, the mass of the dry material and the content of photosynthetic pigments and affected directly the leakage of electrolytic ions, aside from stimulating antioxidant enzymes activity. The GCMS analysis revealed the presence of 22 phenolic compounds, with the emphasis being placed on orientin, luteolin, veratric acid, chlorogenic acid, protocatechuic acid, p-Coumaric acid and ferulic acid, considering that the results were directly proportional to the used concentrations.

ALSAHLI et al. (2018) proved both fungicidal and resistance inductor actions on *Curcuma longa* L. extracts, in the seed treatment of *Helianthus annus* L to control the root rot of *Fusarium solani* (Mart.) Sacc. The GCMS analysis revealed the presence of three main compounds, ar-curcumin, camphor and α-turmerone. The authors determined, besides the reduction in the severity of diseases, the greater growth of sunflower plants. The increase in enzyme peroxidase and ammonia phenylalanine was verified, which indicated the resistance induction. The PCR (polymerase chain reaction) analysis showed the presence of three protein defence regulator genes (glutathione S-transferase 6, ascorbate peroxidase e defensin).

Taking into account the main substances identified by these pieces of research with plant extracts to seed treatment, the phenolic compounds and the terpenes stand out, with the application of controlling Phytopathogenic organisms, insects, herbicide and resistance induction (Table 3).

On account of different potentialities of plant extracts to the employment of agriculture, and considering that they were pointed out in pieces of research over the last ten years, researchers have been trying to identify and isolate compounds that are present in these extracts, including for the application in seed treatment (GHIMIRE et al., 2020; SNEHA et al., 2020; ANŽLOVAR et al., 2020).

It is of paramount importance to discuss the differences in the activities of plant extracts that can be attributed to the different photochemical groups synthesized by plant species. On the other hand, the methodologies employed during the preparation of extracts and their identification are defining and must be the focus of the development of future studies.

In light of all the aspects that were exposed in this review, it is possible to affirm that alternative treatments on seeds, such as the plant extracts employment, are effective and encouraging. It is noticeable that the majority of the studies with plant extracts to the different approaches on the application in agriculture, published in the last 10 years, in particular for seed treatment, support their results exclusively in literature, and just a few of them that determined or identified active substances in the extracts. It was observed that the phenolic compounds and terpenes have been the classes of metabolic composites that are important to the application in agriculture, especially in seed treatment, with emphasis on the control of Phytopathogenic organisms and insects.

CONCLUSION

The period between 2015 and 2020 presented the higher indexes on publication of pieces of research that explored plant extracts in agriculture, seeking to identify or quantify the presence of metabolic composites, indicating a growing interest in this theme. Among the main classes of active composites in plant extracts, the phenolic compounds with different functions, effects and applications in agriculture stand out, mainly in the seed treatment. The terpenes also showed huge potential in relation to the bioinsecticide action. Plant extracts of plant species that are rich in phenolic compounds and terpenes are a significant and promising source to function in the alternative biocontrol of several cropping systems.

In brief, it is observed that the employment of plant extracts for different applications in agriculture, striving for replacing and reducing the use of agrochemicals, consequently, employing ecologic strategies for handling productive systems, has received a lot of attention from researchers in the last few years.

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DECLARATION OF CONFLICT OF INTEREST

The authors declare there is no conflict of interest. The funders did not have any role in the design of the study; in the collection, analysis or interpretation of the data; in the writing of the manuscript and in the decision of publishing the results.

AUTHORS' CONTRIBUTIONS

All authors have contributed equally to the design and writing of the manuscript.

All authors have critically revised the manuscript and approved the final version.

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