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# INSIGHTFUL REVIEW OF BIOHERBICIDES DERIVED FROM PLANTS (PHYTO-HERBICIDES)

*ESRAA E. AMMAR [1], SOHAILA A. ELMASRY [2], SOUMYA GHOSH [3*], AMMAR AL-FARGA [4], YOUSSEF K. GHALLAB [5], ABRAR M. FKR ELDEEN [6], NOURAN A. EL-SHERSHABY [7] AND AHMED A. A. AIOUB [8]*

[1]*Plant Ecology, Botany Department, Faculty of Science, Tanta University, 31527, Tanta, Egypt.*
[2]*Undergraduate Student, Micobiology and Chemistry Specialization, Faculty of Science, Damanhour University, 5845171, Damanhour, Egypt.*
[3]*Department of Genetics, Faculty of Natural and Agricultural Sciences, University of the Free State, Bloemfontein 9301, South Africa.*
[4]*Department of Biochemistry, Faculty of Science University of Jeddah, Saudi Arabia.*
[5]*Postgraduate, Department of Biotechnology, Faculty of Agriculture, Ain Shams University, 11241, Shubra Al Kheimah, Al Qalyubia, Egypt.*
[6]*Postgraduate Student, Botany and Chemistry Specialization, Faculty of Science, Tanta University, 31527, Tanta, Egypt.*
[7]*General Sector, Faculty of Agriculture, Tanta University, 31111 Tanta, Egypt.*
[8]*Plant Protection Department, Faculty of Agriculture, Zagazig University, Zagazig, 44511, Egypt.*

## ABSTRACT

Weed control during crop cultivation with integrated management remains a challenge. Bioherbicides such as plant extracts, allelochemicals, and microbes, are alternatives for weed control in sustainable agriculture. There are a few studies on the physiological influence of plant and microbial biopesticides on the germination and growth of weeds. Weed seed germination or growth is hindered when plant metabolites or extracts are absorbed, damaging the cell membrane, DNA, mitosis, amylase activity, and other biochemical processes. Weed growth is slowed by decreased rates of root-cell division, food absorption, photosynthetic pigment synthesis, and plant growth hormone synthesis, while the production of reactive oxygen species, stress-mediated hormones, and erratic antioxidant activity is increased. Bacterially produced lytic enzymes and toxins degrade the endosperm and utilize it for survival, preventing the growth of weed seeds.

Forty-six plant species were assessed as phytoherbicides against 43 weeds**,** belonging to 19 families and 42 genera. Lamiaceae was the most represented family (21.7%) due to their volatile oils and phytotoxic substances, which eliminate weed growth. *Thymus*, *Eucalyptus* and *Pinus* were the most represented genera. Thirteen species' oils (38 %) and 21 species' extracts (62 %) were used as herbicides. This review provides an overview of the physiological alterations on undesired weeds by using phytoherbicides, which is of the least studied eco herbicides, for sustainable agriculture outlined in the Sustainable Development Strategy 2030.

**Keywords:** Phytoherbicides, Weed control, ROS, Plant oil, Plant extract.

## 1. INTRODUCTION

Weeds are plants that grow in undesirable locations and seriously impede agricultural production [1]. They can serve as hosts for pests and illnesses and compete with crops for resources such as water, gas, nutrients, space, light, and growth-promoting elements [2]. Weeds pose a threat to crop growth factors and reduce yields by an average of 15 to 66% in rice, 18 to 65% in maize, 50 to 76% in soybeans, and 45 to 71% in groundnuts [3, 4].

Depending on the crop, weed management tactics, weed composition, infestation period, and abiotic factors, crop production loss can vary greatly (e.g., climate and soil edaphic factors) [5, 6]. Weed control is a crucial agronomic activity in agricultural farming. Due to a lack of labour, the use of pesticides to reduce weed densities in agriculture is becoming widespread worldwide [7]. Herbicide development, residue in crops, an ecological imbalance between harmful and beneficial organisms, and environmental pollution have all been linked to the extended use of herbicides on a single field to manage weeds [8]. Farmers have been urged to continue using conventional herbicides, which are successful and time- and money-efficient, due to time constraints, developments in pest management technology, as well as a constant "enticement" from the current agricultural system [5, 9].

The use of natural enemies, organic compounds, or biotic agents to limit the germination and growth of weed populations to an economically viable level is known as biological weed control [10]. Mycoherbicides are sprayed onto target weeds with bioherbicides and conventional herbicide treatments being comparable. Recently, bioherbicides have been viewed as an essential component of weed control [11].

Contrary to the use of synthetic herbicides in traditional management, sustainable weed management does not rely on a single strategy; bioherbicides should be employed alongside other weed management techniques to control weeds [12]. Although there are several hundred commercial synthetic herbicides, which make up the majority of market, bioherbicide use is increasing. Because of their effectiveness and advantages, synthetic herbicides have dominated weed control since their introduction roughly 70 years ago. Only 20 different mechanisms of action are present in these herbicides, and most weeds have built up a resistance [13]. This review article gives an overview of the physiological changes that eco-friendly phytoherbicides cause in undesirable weeds as a means of promoting sustainable agriculture in line with the worldwide Sustainable Development Strategy 2030.

## 2. NEGATIVE EFFECTS OF CHEMICAL HERBICIDES

Although successful, herbicides had negative effects on the environment and human health, changed the makeup of weeds, and induced species to become resistant. Herbicides are the most frequently used chemicals globally. Since 2007, herbicides have ranked among the top three categories of pesticides, and worldwide sales of pesticides remained stable during the 1990s [14, 15]. In order to boost agricultural production, herbicide management of weeds has become a standard practice in agriculture. However, when these substances are employed carelessly, they have an effect on organisms that are not their intended targets, particularly aquatic organisms [16].

Herbicides have an impact on the environment, which influences how hazardous they are, how they are distributed and concentrated. Herbicides can have mutagenic effects on organisms including direct impact on DNA and DNA encoding during cell division [17]. Additionally, certain herbicides directly disrupt root or vascular tissue function by interfering with plant cell division, elongation, and differentiation. Herbicides have a wide range of effects on animal tissues and organs, and are occasionally linked to cancer processes [18].

Because phenolic chemicals have physiological effects on membrane functions, membrane potential, mineral uptake, and plant water relations, they prevent the germination of seeds from other plants. Phenolic acid is one of the main allochemicals thought to influence the bioactivity of herbicides in plants. Typically, allelopathic inhibition is caused by the combined action of a number of allelochemicals that interfere with physiological processes [19]. Studies have shown that combinations of allelochemicals that work either additively or synergistically to limit growth are crucial because the concentration of just one chemical under field conditions is lower than the inhibition threshold [20, 21].

Scientists have investigated the drawbacks of pesticides, including the fact that some herbicides are not biodegradable and can last for a very long time in the environment; Every pesticide is at least mildly harmful; can cause illness and even accidental death (paraquat condition); can be absorbed into groundwater or transported into rivers by rainwater [22]; and build-up in the environment damages the food chain, which has an impact on all animals [23]. Benefits of

**Corresponding author email: soumyaghosh@yahoo.com, GhoshS@ufs.ac.za*

pesticides include killing undesirable plants; promote agricultural growth by getting rid of weeds that compete with crops for sunlight, nutrients, and water; field use is safe, as opposed to manually or mechanically removing weeds, which can harm crops; can be applied to crops grown nearby; the pesticide typically only needs to be applied once to control weeds, while alternate techniques must be continuously applied; simple to use, quick to act, reasonably priced, and more cost-effective than manual removal; non-selective herbicides can be used to get rid of vegetation in regions that will be utilized for building homes or roads; and to get rid of disease-carrying plants. Since some herbicides degrade over time, they eventually become inert [24-26]. This review summarizes an overview of the physiological changes brought on by exposure to bioherbicides in weed growth.

## 3. BIOCHEMICAL ACTION OF HERBICIDES

Herbicides kill through obstructing biochemical, physiological, or both mechanisms. The compounds target proteins or enzymes that are involved in fundamental metabolic pathways. Herbicides have been used to research physiological and biochemical processes in plants since they have selective target areas. The mechanisms of herbicidal action have not been reviewed extensively and until recently, no compilation of herbicide target site assays were found. Inhibition of p-hydroxyphenylpyruvate dioxygenase, extremely long fatty acid elongation, cellulose biosynthesis, serine/threonine protein phosphatases, and deoxyxylulose-5phosphate synthase are a few examples of new mechanisms of action that have been mentioned [27, 28] **(Fig. 1.** and **Fig. 2**).

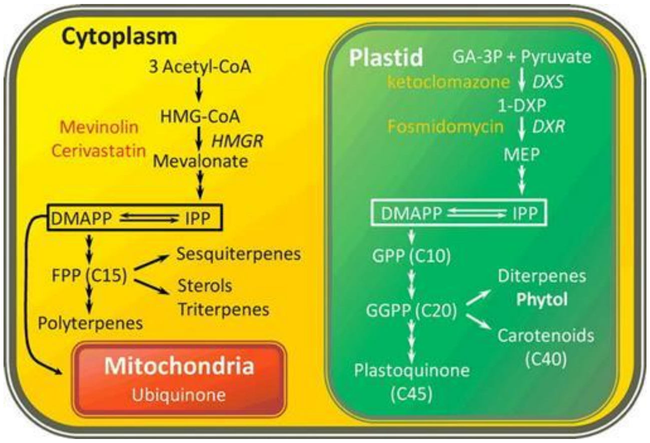

**Fig. 1.** Diagram showing the compartmentalised 1-deoxy-d-xylulose 5-phosphate (DOXP) or 2-C-methyl-d-erythritol 4-phosphate (MEP) route in the plastid and the mevalonic acid (MVA) pathway that is located in the cytoplasm (Dayan et al. 2010).

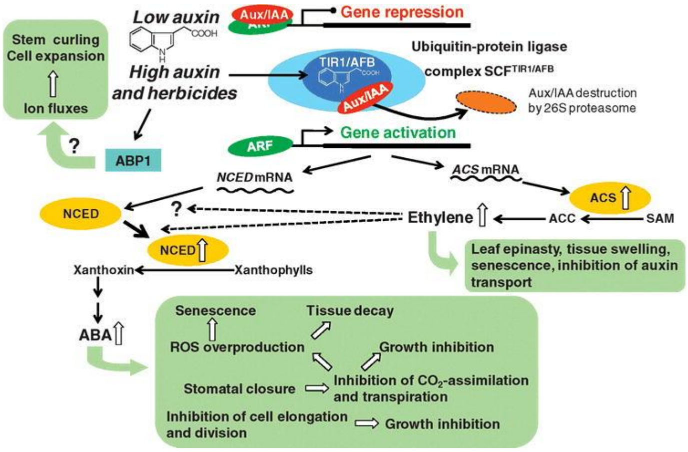

**Fig. 2.** Supraoptimal levels of indole-3-acetic acid and auxinic herbicides' proposed mechanisms of action (IAA). For a thorough explanation of the action's process, see the text. ACC: 1-aminocyclopropane-1-carboxylic acid; ACS: ACC synthase; NCED: 9-cis-epoxycarotenoid dioxygenase; ABP1: auxin-binding protein 1; ABA: abscisic acid; ROS: reactive oxygen species; TIR1/AFB: auxin receptors; Aux/IAA: transcriptional repressor proteins; ARF (Dayan et al. 2010).

The ability to react to environmental changes, which enables them to regulate and adapt to a changing ecology, is a crucial property of plant tissues. Drought, heat, cold, salinity, nutrient deficiency, and oxidative stress are just a few of the environmental changes that have a significant impact on plant productivity. These conditions cause plants to respond morphologically, physiologically, and biochemically [29, 30].

One of the main effects of biotic and abiotic stress on a plant's physiological and biochemical metabolism is oxidative stress; as a result, it's critical to have a healthy balance of reactive oxygen species (ROS) that scavenge antioxidant proteins and enzymes [31]. Reactive oxygen species are implicated in numerous studies as the primary driver of cell deterioration. These oxidizing molecules develop during biotic and abiotic stresses and produce harmful hydrogen peroxide, superoxide, and hydroxyl radicals when oxygen is reduced by 1, 2, or 3 electron transfers. Protein denaturation and lipid peroxidation is caused by the process, which is harmful to biomolecules including lipids, proteins, and nucleic acids [32, 33]. Cellular membrane interaction with unsaturated fatty acids to generate peroxidation of the lipid bilayer in cellular and intracellular environments, is the main location of cellular and organic harm by ROS [34].

Intercellular damage affects the respiratory activity in mitochondria and results in pigment breakdown in chloroplasts. Cellular damage consequently causes leakage of cellular contents, rapid desiccation, and, inevitably, cell death [35]. Normal cell metabolism generates ROS in similar amounts in photosynthetic organelles such as chloroplasts, and photorespiration organelles such as mitochondria, and peroxisomes. The release of single active chemicals that control photosynthesis, flower senescence, pollen growth, root formation, and root hairs is how ROS typically operate as an oxidant of proteins and lipids [5, 36].

Reactive oxygen species are produced by plants, but are eliminated when they reach dangerous amounts by the antioxidant defence system. Reactive oxygen species overproduction and build-up cause metabolic abnormalities and can result in oxidative cell death. Numerous stimuli enhance the generation of ROS and produce oxidative stress in plants, including weeds and crops. The antioxidant system's role in weed interference and herbicide treatment of crops and weeds has been the subject of research and is regarded as a crucial metabolic reaction of herbicides against weeds [37, 38]. An additional biochemical herbicide strategy includes catalase (CAT), mono-dehydroascorbate reductase (MDA), peroxidase (POD), superoxide dismutase (SOD), guaIacol peroxidase (GPX), and glutathione reductase (GSH) activity on weeds [39, 40].

## 4. BIO HERBICIDES FROM PLANT EXTRACTS

Bioherbicides for sustainable weed management in agriculture may be an alternative to the traditional use of plant extracts for medical or nutritional purposes. Bioherbicides made from natural extracts have demonstrated promising results against weeds. Several plant extracts have a specialized inhibiting function against weed growth, but do not harm crops [41]. This could be explained by the sensitivity of the target enzymes or the presence of distinct receptors in weeds, which recognize and respond to the chemicals [42]. Certain plant species have the ability to emit compounds known as allelochemicals, including alcohols, fatty acids, phenolics, flavonoids, terpenoids, and steroids, which inhibit reproduction, growth, and development of nearby flora, including weed species [43].

Weed seeds absorb plant extracts or metabolites, which causes damage to the cell membrane, DNA, mitosis, amylase activity, and other biochemical processes. This delays or prevents seed germination. Weed development is further slowed by decreased rates of root cell division, food absorption, photosynthetic pigment synthesis, and plant growth hormone synthesis, while elevated levels of ROS and stress-mediated hormones, including irregular antioxidant activity are produced [5, 44] (**Fig. 3**). Development of environmentally acceptable bioherbicides may be facilitated by using plant species that have allelopathic effects on weeds [45].

A substantially untapped reservoir of phytotoxins that can be employed directly or as structural markers of novel synthetic herbicides is present in plants and bacteria. The herbicide business has developed a great interest in this organic source due to a number of factors [46, 47]. While these substances have only had sporadic success as herbicides, they have had a substantial impact as insecticides.

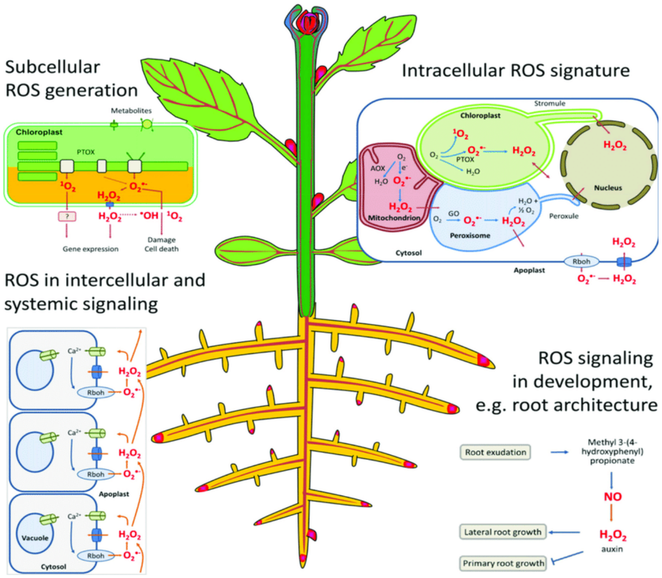

**Fig. 3.** Roles of reactive oxygen species (ROS) involving multiple regulations in different cellular compartments of a plant (Hasan et al., 2021a and b).

When discovering and creating a natural product as a herbicide, there are more options to take into account than with synthetic herbicides. Many phytotoxic natural compounds are disappointing due to their high molecular complexity, poor environmental stability, and ineffectiveness as herbicides. However, developments in chemistry and biotechnology are speeding up and simplifying processes by which we can discover and create herbal pesticides using natural components [46, 47].

## 5. MODE OF ACTION OF PLANT PRODUCTS AS PHYTOHERBICIDES

"The term mode of action refers to the sequence of events from absorption into plants to plant death. A herbicide's mode of action influences the application thereof. For example, contact herbicides that disrupt cell membranes, such as acifluorfen (Blazer) or paraquat (Gramoxone Extra), need to be applied post emergence to leaf tissues to be effective. Seedling growth inhibitors such as trifluralin (Treflan) and alachlor (Lasso), need to be applied to the soil to effectively control newly germinated seedlings [48, 49]. To be effective, herbicides must contain suitable botanical compounds, be absorbed by the plants and transmitted within the plants to the required site, without inactivation and reach toxic levels. The application method used, whether pre-plant or post-emergence, determines whether the herbicide will come into contact with germinating seedlings, roots, buds, or leaves of plants [48].

Numerous studies highlight the bioherbicidal effect of plant extracts, bacteria, fungi and other products, especially with regard to weed germination and growth, but few studies have been conducted to determine the mode of action and physiological changes in weeds. A biocidal method similar to the reaction mechanism of plant pathogens and allelitis was developed. In the case of plant pathogen interactions, the biocontrol agent must bypass defensive reactions of the herb and both must be compatible in order for the pathogen to infect the plant. The pathogen initiates the infection process by producing enzymes that degrade plant cell walls, proteins and lipid membranes, facilitating their entry. However, for a toxic effect that results in plant death, a specific receptor or enzyme is required in the plant for a specific poison and this mechanism is considered biochemical [50]."

Herbicides affect plants at tissue or cell levels. Herbicides with the same mode of action will have the same pattern of displacement (action) and produce similar infestation symptoms. The selectivity on crops and weeds, soil behaviour and application patterns are less predictable, but are often similar for herbicides with the same effect. In addition to plants, many herbicides are applied to the soil. Herbicides are applied almost strictly to the soil. Mechanism of action and mode of action are often used interchangeably, however, mechanism of action refers to the specific plant process by which a herbicide intervenes to control weeds. Mode of action refers to all herbicide reactions. Herbicides kill plants in different ways [51, 52].

Subjectively, the answer to the issue differs substantially in terms of type of approach and type of answer. A specific pre-emergent herbicide may react when absorbed by the soaked seed with significant inhibition of the seedling's root development. The fast removal of established leaf tissue by post-emergent barberry in sunshine, may provide the solution. These responses incorporate visual data. But during the past few years, knowledge has accumulated about the cellular, physiological, biochemical, and molecular aspects of insecticidal activity on various plant systems [53, 54].

Six distinct forms of data can be separated in order to categorize the knowledge that is currently known regarding the mechanism of herbicidal action. The mechanism of action of novel herbicides may be made clearer using this classification as a reference. There will always be information available on application technologies. This information enables the substance to be categorized as a desiccant, contact herbicide, bleaching herbicide, or hormone destroyer. Microradiography or cell segmentation of tissue homogenates can be used to gather information on the accumulation of radiolabelled herbicides. The preferential concentration of herbicides in a specific subcellular structure, such as a chloroplast, does not, however, suggest that this organelle is the location of activity or even includes it. As a result, subcellular fusion, for instance, is the earliest sign of visual impairment. The presence of the chloroplast membrane does not necessarily indicate that this organelle is located at the impact site. Therefore, it has not been demonstrated that the information on cellular action is extremely helpful in identifying the principal site of action, despite the fact that it may be intriguing and relevant in relation to other discoveries on herbicide interactions [54, 55].

## 6. ESSENTIAL OIL, PLANT EXTRACT AND OTHER SOURCES FOR HERBICIDES

Beside essential oils being used as insect repellents and herbicides, they are renowned for their medicinal potency. Finding natural weed control options is essential since synthetic herbicide use has led to the evolution of resistant weeds. Three commonly used commercial essential oils include *Eucalyptus citriodora*, *Lavandula angustifolia*, and *Pinus sylvestris*. These oils can be used on food crops like tomatoes and cucumbers as well as invasive species like *Nicotiana glauca* and weeds like *Portulaca oleracea*, *Lolium multiflorum*, and *Echinocloa crus-galli* [56] (**Table 1**).

Essential oils are isolated from plants are used as herbicides and have medicinal and aromatic properties, and include *Origanum syriacum*, *Micromeria fruticosa*, *Cymbogon citratus*, *Thymus vulgaris*, *Mentha spicata*, *Osmium Basilicum*, *Salvia officinalis*, *Thymbra spicata,* and *Eucalyptus* spp. [41, 57-63] (**Table 1**). Additionally, some weed seeds are less susceptible to certain essential oils than others and control oils [64] (**Table 1**).

Research showed that oils had phytotoxic effects on the germination of weed seeds and the growth of seedlings of weeds such as *Sinapis arvensis*, *Lolium rigidum*, and *Phalaris canariensis*. It was discovered that the essential oils significantly and dose-dependently inhibited the germination and growth of the seedlings, with *S. arvensis* being more sensitive to their effects than *P. canariensis* and *L. rigidum*. Essential oils inhibit weeds' roots and aerial parts. Essential oil treatment had a significant impact on the strength of weed seedlings, which in the field decreased their competitiveness and probably enabled the developed crops to utilize soil nutrients and water more effectively [65, 66] (**Table 1**).

Other herbicides may be leaf or plant extracts such as *Ammi visnaga*, *Juglans nigra*, *Aglaia odorata*, *Aylanthus altissima*, *Cynara cardunculus*, *Mimosa pigra*, *Myrothecium roridum*, *Sinapis alba*, *Rumex dentatus*, *Dalbergia sissoo*, and *Lantana camara*. The herbicides may also cause a lack of germination or inhibition of weed growth and other symptoms [44, 67-77] (**Table 1**).

## 7. ASSESSMENT OF PLANT SPECIES USED AS PHYTOHERBICIDES

From literature, 46 plant species were assessed as phytoherbicides against 43 weeds (**Table 1**). The 46 species belonged to 19 families and 42 genera (**Table 2**). Lamiaceae was the most represented family (10 species = 21.7%), then Asteraceae (7 species = 15.2 %) and Fabaceae (5 species = 10.8 %) due to their volatile oils and phytotoxic substances, which eliminate growth of weeds (**Table 2**) (**Fig.4**). *Thymus*, *Eucalyptus* and *Pinus* were the most represented genera (**Table 1**). The oils of 13 species (38 %) and the plant extract of 21 species (62 %) were used as herbicides [78].

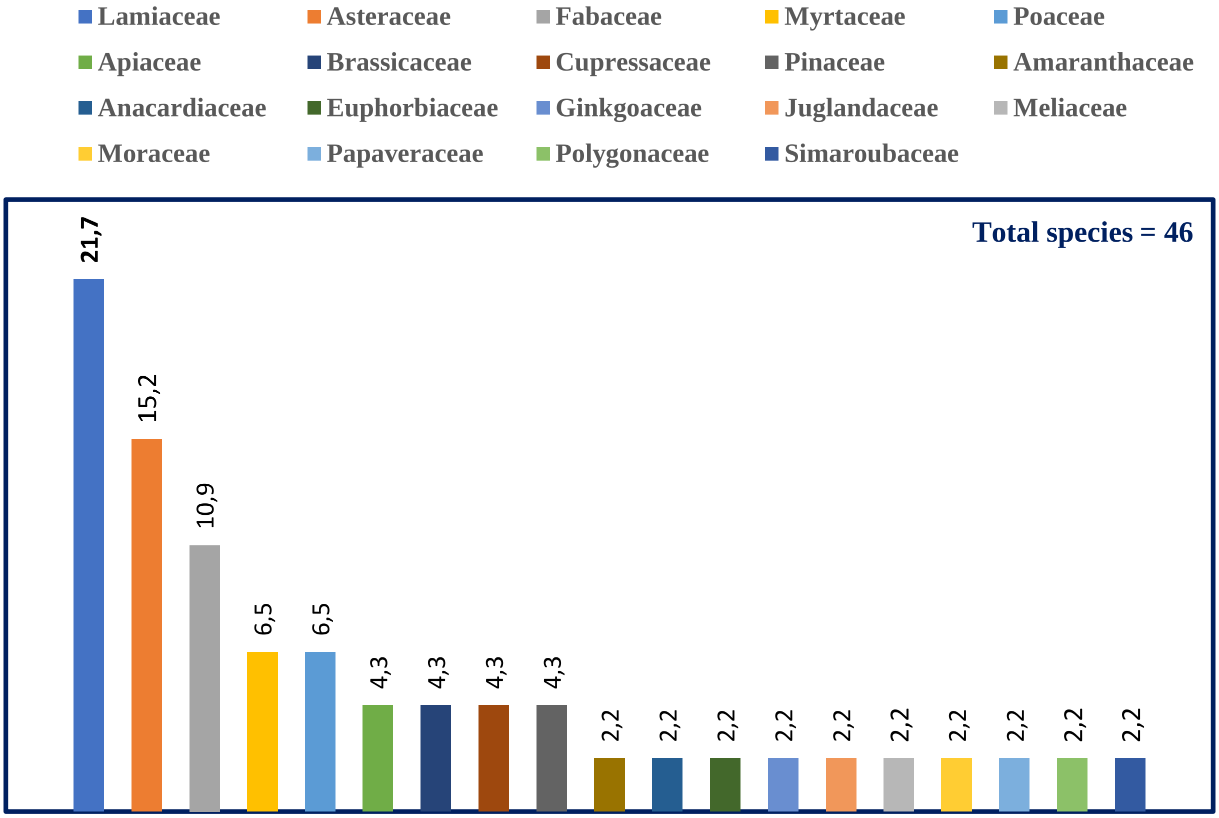

**Fig. 4.** Most represented families of the detected 46 plants species used as phytoherbicides.

## 8. KNOWLEDGE GAPS AND FUTURE PERSPECTIVES

To achieve food security for humans and good health within the framework of the United Nation’s goals, recent scientific research in smart agriculture supports the use of eco-friendly bio-degradable products extracted from algae, fungi, plants, and animals as biofertilizers, bioherbicides, bioinsecticides, and biopesticides. These products reduce soil stress and prevent the accumulation of toxic substances in the tissues of agricultural crops, particularly food [79-81]. Due to their capacity for biodegradation and lack of accumulation of toxins in soil and plant tissues, these compounds are both safe and environmentally beneficial [79]. Currently there is little research on using plants as phytoherbicides. Modern biotechnological and nano-technological research should be directed to develop herbicides extracted from plants to decrease weed growth in various climatic conditions [5].

In the future, the use of biodegradable bioherbicides will be recommended rather than chemical herbicides, because of their safety on cultivated plants, soil and surrounding environment. In addition, they will increase the soil fertility without any accumulated residues. Mixing of nanomaterials to bioherbicides will offer nanotechnological green alternatives for the management undesirable weeds with enhanced cultivation of desirable plants. The manufacture of herbicides from plant extracts and oils will be recommended as authorized commercial products. Furthermore, the elevation of the environmental awareness of farmers on use of phytoherbicides will benefit production and quality of desired plants (e.g., crops, fruits, ornamentals) in addition to preserving soil structure and fertility in the long-term.

## CONCLUSION

Managing weeds while growing crops using integrated management is difficult. The use of bioherbicides is an innovative technique for weed control in sustainable agriculture. Weed populations are managed with bioherbicides such as plant extracts, allelochemicals, and certain microorganisms. Despite the fact that weeds can be prevented from germinating and growing by using biopesticides based on plants and microbes, very little research has been done on the physiology of weeds.

Using phytoherbicides as one of the eco-friendly bioherbicides will support sustainable agriculture according to the Sustainable Development Strategy 2030 globally. They are biodegradable and more beneficial for getting rid of weeds without harm to the desired cultivated plants, where they have specific targets. Each phytoherbicide targets specific species of weeds, making them safer for soil structure and a natural elevation in fertility, in addition to bio-agriculture without synthetic materials.

## ETHICAL APPROVAL

Not applicable.

## CONSENT TO PARTICIPATE

All authors are consent to participate.

## CONSENT TO PUBLISH

All authors are consent to publish**.**

## AUTHORS CONTRIBUTIONS

Esraa E. Ammar, Ahmed A. A. Aioub, Soumya Ghosh, Ammar AL-Farga and Sohaila A. Elmasry interpreted, conceptualized, corrected, and completed the final manuscript. Youssef k. Ghallab, Abrar M. Fkr Eldeen and Nouran A. EL-Shershaby provided technical corrections and suggestions for the final manuscript. All authors critically reviewed the final manuscript for submission.

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## COMPETING INTERESTS

No conflict of interest.

## AVAILABILITY OF DATA AND MATERIALS

Available via corresponding author.

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