Revista Brasileira de Herbicidas, v.15, n.1, p.116-125, jan./mar. 2016 (ISSN 2236-1065)
DOI: http://dx.doi.org/10.7824/rbh.v15i1.452 www.rbherbicidas.com.br

# Biological weed management – A short review[1]

## *Manejo biológico de plantas daninhas – Breve revisão*

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**Abstract -** At present, reducing the use of pesticides is sought out, for besides the environmental damage caused by them, there is concern about the consumption of food contaminated with possible residues. This literature review aims to address the use of bioherbicides, besides evaluating their prospects and potential to manage weeds infesting agricultural and nonagricultural environments. There is a growing need to find new molecules or methods able to control weeds found in agricultural and nonagricultural areas. Thus, bioherbicides have aroused the interest from researchers, technicians and producers. These can be formulated from substances produced by the secondary metabolism of plants and/or microorganisms. Research conducted points to efficient control with the use of bioherbicides, mainly related to the germination processes and development of weeds, and in some cases have a phytotoxic potential even when these are in advanced stages. Herbicides, in addition to being effective in weed control, reduce environmental damage caused by continuous use of synthetic herbicides. Brazil has the potential to use bioherbicides aiming to have plant diversity and the various agricultural crops systems practiced in the country.
**Keywords:** biological control; alternative herbicides; environmental sustainability

**Resumo** - Na atualidade busca-se reduzir o uso de agrotóxicos, pois além dos prejuízos ambientais provocados por eles, existe a preocupação com o consumo de alimentos contaminados com possíveis resíduos. A presente revisão de literatura tem como objetivo abordar o uso de bioherbicidas, além de se avaliar as perspectivas e as potencialidades desses como formas de manejo de plantas daninhas infestantes de ambiente agrícola e não agrícola. Há a necessidade crescente de se descobrir novas moléculas ou métodos capazes de se controlar as plantas daninhas infestantes de áreas agrícolas e não agrícolas. Assim sendo os bioherbicidas vem despertando o interesse de pesquisadores, técnicos e produtores. Estes podem ser formulados a partir de substâncias produzidas pelo metabolismo secundário de vegetais e/ou de microrganismos. As pesquisas realizadas apontam o controle eficiente com o uso de bioherbicidas, principalmente relacionados aos processos de germinação e desenvolvimento das plantas daninhas, podendo em alguns casos apresentar potencial fitotóxico mesmo quando essas estiverem em estádios avançados. Os bioherbicidas, além de serem eficientes no controle das plantas daninhas, reduzem os prejuízos ambientais provocados pelo uso contínuo de herbicidas sintéticos. O Brasil apresenta potencial para se usar os bioherbicidas, tendo em vista a diversidade vegetal e os diversos sistemas de cultivos agrícolas praticados no país.
**Palavras-chaves:** controle biológico; herbicidas alternativos; sustentabilidade ambiental

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## Introduction

The agricultural activity has contributed to the worsening of problems related to the environment and have often left in the background the issues surrounding the agro-ecosystems sustainability (Leite et al., 2011). Environmental degradation processes contribute to a reduction in food production and an increase in pests (diseases, insects and weeds) that can cause significant losses in productivity and quality of food produced.

In this sense, the use of herbicides for weed control can contribute to this process of environmental degradation. In view of the need to control their germination, growth and development, the application of herbicides is one of the methods used by farmers to increase or even maintain agricultural productivity. As a result, the consumption of pesticides in Brazil is growing (Veiga et al., 2006). Besides the need for control in the field, there is also the application of synthetic herbicides on weeds in highways, railways, lawns, among others. This continuous and indiscriminate use has aroused great concern in view of the negative consequences for agricultural ecosystems, the applicators contamination and possible residues in food.

Faced with the problems caused by the use of pesticides and the need to search for sustainability of agro-ecosystems, the discovery of bioherbicides can be an interesting tool. The use of natural products proves to be an important technique to reduce environmental pollution, and it does not prevent the natural ecological processes, such as plant dominance, ecological succession, formation of communities and climax vegetation (Silva et al., 2007a). Research about alternatives based on natural products for weed control is extremely important today, even to control weeds tolerant or resistant to many synthetic herbicides.

The first research evidence seeking biocontrol emerged in mid 1836 (Goeden, 1983). From the sustainable and ecological point of view, biological control is probably the most desirable method. Thus, phytophagous insects, plant pathogenic fungi, plant pathogenic bacteria, plant pathogenic viruses, fish, crustaceans, birds and plant extracts containing allelopathic or phytotoxic substances can be understood as biocontrol agents.

Sustainability, environmental safety and potential effectiveness of control are appointed by Nachtigal (2009) as important factors to the growing interest in the use of different strategies known for biological control. Natural products have been an alternative to weed control, from the development of bioproducts based on the principles of sustainability (Ootani et al., 2013). In this sense, the present literature review aims to address the use of bioherbicides, and to evaluate their prospects and potential as ways for weed management infesting agricultural and nonagricultural environments.

## Weeds: Control with the Use of Bioherbicides

The natural herbicide produced from plants (Table 1) or pathogens to control weeds is called bioherbicide and most of the studies are focused on the use of fungi (Klaic et al., 2015). The use of fungi and/or plants in biological control techniques is an important alternative in view of the potential use with less impact on natural resources and less contamination of food and the applicator (Padin et al., 1995).

However, it is possible to briefly say that for a toxin to be successfully used in weed biological control, the following characteristics may be in place: it should be phytotoxic for the weed, selective to the crop, water soluble to facilitate spraying, cause low environmental impact, and not contaminate the food and the applicator (Tremacoldi and Souza Filho, 2006).

There are several reasons that lead to producing allelochemicals-based bioherbicides. Among them, stand out: the growing number of biotypes of weeds resistant to synthetic herbicides, the search for agricultural systems sustainability, the need for products with low toxicity to mammals, high specificity and rapid degradation by the microorganisms present in the soil, etc. (Tremacoldi and Souza Filho, 2006). In this regard, the discovery of new herbicides based on natural products is interesting from the social, cultural and environmental points of view (Gomes et al., 2013), but mostly from the agronomic one, because of the chance to obtain an alternative control for plants resistant to herbicides, and lower environmental impact.

**Table 1.** Research conducted with plant-based bioherbicides.

| Author – year | Weed and/or Plant control | Plant with allelopathic pontential |
|---|---|---|
| Pires et al., 2001 | *Bidens pilosa*; *Amaranthus hybridus* | *Leucaena leucocephala* |
| Goetze e Thome, 2004 | *Brassica oleracea* var. *itálica*; *Brassica oleracea* var. *capitata*; *Lactuca sativa* | *Eucalyptus grandis; Nicotina tabacum* |
| Wandscheer et al., 2011 | *Lactuca sativa* | *Hovenia dulcis* |
| Moraes et al., 2012 | *Bidens* sp.; *Digitaria* sp.; *Zea mays* | *Trifolium vesiculosum* |
| Cipriani et al., 2014 | *Handroanthus ochraceus*; *Lactuca sativa*; *Medicago sativa* | *Tecoma stans* |
| Diógenes et al., 2014. | *Lactuca sativa* | *Ziziphus joazeiro* |
| Nunes et al., 2014 | *Cucumis sativus*; *Glycine max*; *Lactuca sativa* | *Brassica napus; Crambe abyssinica; Crotalaria juncea; Linum usitatissimum; Raphanus sativus* |
| Albuquerque et al., 2015 | *Bidens pilosa*; *Cenchrus echinatus*; *Desmanthus virgatus*; *Senna obtusifolia* | *Azadirachta indica* |
| Sartor et al., 2015 | *Bidens pilosa*; *Lactuca sativa*; *Zea mays* | *Pinus taeda* |

Currently, allelopathic substances derived from the acetate pathway or shikimate pathway (shikimic acid pathway) or the two combined to the formulation of natural herbicides have been used. These allelochemicals belong to several classes such as terpenes, alkaloids, phenolics, steroids, long chain fatty acids, unsaturated lactones, benzoxiazinones, cinnamic acid derivatives, coumarins and cyanogen compounds (Sartor et al., 2015).

There are several chemicals synthesized from compounds naturally occurring and derived from plants or microorganisms and among them can be mentioned: Anisomycin isolated from *Streptomyces* sp., commercialized under the name Methozyphenone; Cineole, isolated from various plants and commercialized under the name of Cinmethyline; Quinolinic acid from *Nicotiana tabacum*, commercialized under the name Quinclorac (Hatzios, 1987).

It should be noted that after the discovery of natural substances with herbicide potential, one should follow the same rules of pesticides in general for the processes of formulation, standardization, packaging and marketing (Tessmann, 2011).

Although there are several advantages in using natural herbicides, there are also some disadvantages, among which it is possible to highlight the problems regarding their development and commercial use, in view of the dependence of the agents efficiency in relation to environmental factors in production, storage, transportation and application (Tessmann, 2011). Furthermore, the development of a new herbicide molecule based on natural substances is a complex process and demands a lot of investment (Guerra et al., 2014).

In biocontrol, it is important to consider the genetic diversity of the hosts, since in many cases the plant pathogens are very specific. Often these microorganisms have the *formae specialis* restricting the use to only one species of plant (Ash, 2010). Also in certain situations, even if they control a wider range of weed species, their use is prevented due to causing damage to the crop of interest. Another problem faced is the cost, both in the process and in the record, because bioherbicides must be competitive with synthetic herbicides in terms of price, effectiveness, practicality and application technology (Ash, 2010). It can also be seen that research on bioherbicides receives less support compared with research on conventional chemicals. Long-term investments coupled with lack of support from administrators and funding agencies have been the biggest obstacles in the introduction of biological control (Klaic et al., 2015).

Generally, the cost of fermentation of microorganisms is higher than the cost to produce synthetic pesticides. Therefore, to be competitive in the market, microbial isolates should present high potential for control and yield during production. By considering the high price in the early stages of production, many companies avoid the development of unprofitable products.

However, there are examples that the development cost is not always a barrier, as in the case of Constans®, where the property holding company has saved in the early processes of mass production of spores to ensure commercial viability, and Serenade®, and these two products are competitive in price compared to synthetic products (Klaic et al., 2015).

In recent years, there have been conferences to discuss the future and prospects of new biocontrol agents. An example was the *Australian and New Zealander Conference of biocontrol: Emerging issues and future prospects* (Gurr et al., 2010). And Brazil had in the *Brazilian Congress of Weed Science (2014)* some debates where issues related to new ways of weed management were discussed. However, for the biological control to be established as an alternative way to control weeds, further support to research in this area is necessary, so that new technologies are developed and the old ones are improved.

## Animals-based Bioherbicides

Weed control with animals has been used in specific situations and usually in places where small crops are grown. Producers have been using sheep to control weeds in coffee plantations, but some species do not have good palatability, being left aside during grazing (Silva et al., 2007b), and this becomes a serious problem, since it starts a species selection process that can later dominate the environment.

Herbivore fish (carp, Pseudocrenilabrinae and others) have been used for the management of aquatic plants (Miyazaki and Pitelli, 2003). The same authors have found control of up to 100% of the species of *Egeria densa* and *E. najas* and of *Ceratophyllum demersum* using fish pacú (*Piaractus mesopotamicus*). Fish have also been used in crops and intercropping for the control of weeds seeds infesting irrigated rice, especially grass carp (*Ctenopharyngodon idella*) in crops in the Brazilian state of Santa Catarina (SOSBAI, 2014). In that same state, Pekin duck has been used since 1990, having at the time a reasonable use by farmers (Eberhardt et al., 2003). Garganey and fish (Figure 1) would be used mainly by small farmers to control the weed seed bank, especially weedy rice (red and black rice) and other species, before settling the irrigated rice crop.

However, many farmers who have experienced the technology have not effectively adopted it due to the low availability of garganey in the market or to little success in controlling red rice (Eberhardt et al., 2003). Farmers would also aspire to get an additional income from the sale of garganey after use, and this has not effectively occurred due to the low demand for this type of meat (Eberhardt et al., 2003). Fish and Pekin duck can significantly reduce the infestation of existing weeds in crops using this method of control.

According to Eberhardt et al. (2002), there is efficiency in the use of drakes to control red rice seeds located on the soil surface (Figure 2) when finding 339 whole seeds of the weed in the stomach contents of an animal. However, the authors report that the garganey cause less reduction in the seed bank located in deeper layers of soil when comparing with more superficial layers.

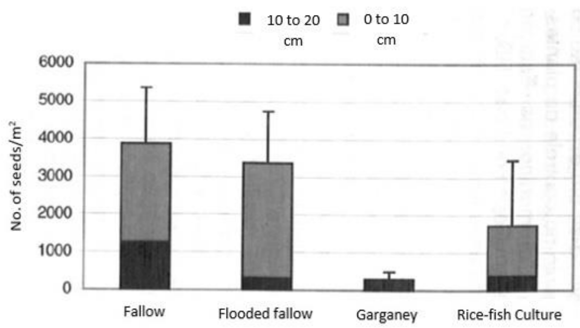


**Figure 1.** Red rice seed bank in the soil, 130 days after the settlement of the garganey. Epagri, experimental station in Itajaí, SC, 2003. Source: Adapted from Eberhardt et al. (2003).

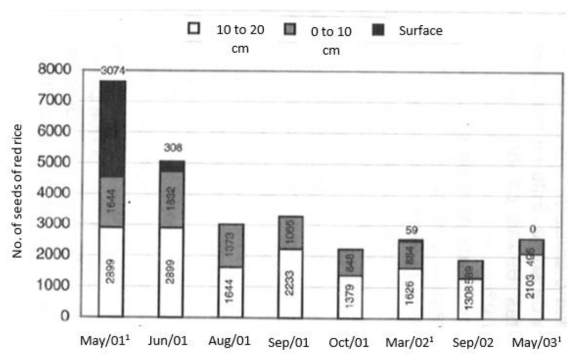


**Figure 2.** Red rice seed bank evolution in the soil in the area occupied with garganey. Epagri, Ilhota, SC, 2003. Post-harvest assessment and settlements of garganey. Source: Adapted from Eberhardt et al. (2003).

The use of Pekin duck becomes a viable alternative to control the weed seed bank located on the ground surface without the soil being plowed (Eberhardt et al., 2003).

## Bioherbicides based on fungi, bacteria and/or insects

In addition to the tests with vegetable allelopathic substances, there is research aimed at the use of microorganisms for biological control. In the vast majority, biocontrol is focused on the use of microorganisms and these can be plant pathogens or produce phytotoxic components. Fungi, bacteria and metabolites for basic biological processes also produce secondary metabolites and are so called because they do not have any role in primary metabolism (Bell, 1981). The importance of these secondary metabolites is due to the fact that their phytotoxicity is specific, that is, it presents efficacy and selectivity to a particular species, such as from weed or crop, and may thus constitute an important source for the development of new herbicides being used in direct form or as a model for the manufacture of molecules for new agrochemicals (Zimdahl, 1993). These metabolites are not essential for the growth of the microorganism, but are excreted and present in the culture medium or the substrate in which these fungi grow. When they are toxic to plants they are called phytotoxins (Klaic et al., 2015).

Among the phytotoxins with herbicidal properties produced by fungi are the AAL toxins. They have different action mechanisms, one of which is the interruption of the production of chloroplasts by blocking the synthesis of the nucleocytoplasmic protein, and the other is the inhibition of the energy generated by ATPase, an additional factor controlling photophosphorylation (Li et al., 2003). AAL toxins and other bases have proven to be effective in the escape of electrolytes and loss of chlorophyll in concentrations around 20-40 nM (Abbas et al., 1998).

Research related to compounds in secondary metabolism of these organisms that may have a herbicidal effect has generally been carried out from prospecting species, cultivars, or accessions, and may be followed by isolation and identification of active compounds (Dias and Dias, 2007). Usually, research tends to start with experiments on activity and range of hosts, usually in greenhouses, and studies on the epidemiology to define the optimal conditions for infection. On a smaller scale, there are experiments that seek to demonstrate the potential of biocontrol in real field situations (Dias and Dias, 2007).

For sufficient inoculum manufacture, small-scale fermentation is performed to produce spores or mycelia and in this case testing different formulations and adjuvants is required. At this stage, the control agent can be presented to a company that can invest in its production (Ash, 2010).

There are two strategies in which microorganisms are used for biological weed control: the classic method and the inundatory method. The classic method is the import, introduction and release of a natural enemy that has the same geographical origin of the weed in an area where this plant is a problem. After release, the pathogen is allowed to perpetuate, survive and settle, thus providing weed control in the long term over a long period (Boyetchko et al., 2002). Usually this process is most commonly used in pastures where disturbance is minimal (Klaic et al., 2015).

The inundatory method is defined as the use of the pathogen through flood and repetitive inoculum applications (Charudattan and Dinoor, 2000). Pathogens are often wild, mass-produced in laboratories and applied during the weeds growing season. Control is short-term, compared to the classic method, and the biological agents should not persist in the environment. Most microorganisms used as herbicides are predominantly pathogenic fungi (Klaic et al., 2015).

The beginning of the use of fungi as weed control in the form of biocontrol occurred in 1971 with the fungus *Puccinia chondrillina*, which was introduced in Australia to control *Chondrilla juncea* (Klaic et al., 2015).

The first bioherbicide registered for commercial use in the United States was DeVine®, which was a liquid formula consisting of *Phytophthora palmivora* soil fungus chlamydospores to control *Morrenia odorata* in citrus (Boyetchko et al., 2002). This product controls weeds with rates above 90% and the control may persist for two years (Li et al., 2003). In that same country, fungus *Colletotrichum gloeosporioides* is used to control zigzag jointvetch (*Aeschynomene virginica*) infesting soybean, maize and especially irrigated rice crops, and this natural herbicide is registered as Collego® (Silva et al., 200b).

To control Chinese senna or sicklepod (*Senna obtusifolia*) the product Casst® was developed, based on the fungus *Alternaria cassiae*, and for *Malva pusilla* the product with the fungus *Colletotrichum gloeosporoides* f.sp. *malvae* was created, trade mark Biomal® (Victoria Filho et al., 2014).

Insects are also used for biological control of weeds infesting crops. In Australia, insect larvae (*Cactoblastis cactorum*) were used to control cacti (*Opuntia* spp.), and in Hawaii, Lantana camara (*Lantana câmara*) was controlled by insects *Agromisa lantanae* and *Crocidosema lantanae* (Silva et al., 2007b).

In Brazil, isolates of *Fusarium graminearum* have been studied as agents for biological control of *E. densa* and *E. najas*, aquatic plants that cause problems in the aquatic environment (Silva et al., 2007b). However, it is known that the photoperiod influences the control efficiency of the species by the fungus and temperatures above 30 °C cause better control of *Egeria* (Borges Neto et al., 2005).

Currently, there are several studies that use microorganisms, especially fungi, in weed control and/or testing plants. Some of these results are shown in Table 2.

Among the leading producers of toxins are genera *Aspergillus, Penicillium, Fusarium, Claviceps, Alternaria, Strachybotrys, Mycrothecium, Phoma* and *Diplodia* (Tremacoldi and Souza Filho, 2006). However, despite proving to be effective, herbicides based on natural fungi are methods restricted to specific locations, as environmental variations influence the efficiency and in many cases even selectivity. As, for example, fungi *Rhynchosporium alismatis* (sin. *Plectosporium alismatis*) and *P. tabacinium* are efficient to control *Sagittaria pygmaea, S. guayanensis* and *S. trifolia*. However, field application of these mycoherbicides is hampered by biological, technological, environmental and economic constraints (Chung et al., 1998). Among other obstacles to develop herbicides with pathogenic fungi are the need for long periods of wetting, low fertility, low virulence (Barreto, 2009) and also the specificity that these agents have on the weeds occurring in crops; in rare cases, a single weed species is responsible for the infestation.

**Table 2.** Fungal species with a phytotoxic effect on plant species.

| Fungal species | Plant | Author |
|---|---|---|
| *Fusarium nygamai* | *Striga hermonthica* | Abbasher & Sauerborn (1992) |
| *Colletotrichum orbusculare* | *Xanthium spinosum* | Auld and Say (1999) |
| *Fusarium tumidum* | *Ulex europaeus* | Morin et al. (2000) |
| *Phytophthora palmivora* | *Morrenia odorata* | Boyetchko et al. (2002) |
| *Puccinia lagenophorae* | *Senecio vulgaris* | Grace and Schärer (2003) |
| *Phomopsis amaranthicola* and *Microsphaeropsis amaranthi* | *Amaranthus* sp. | Ortiz-Ribbing and Williams (2006) |
| *Colletotrichum coccodes* | *Abutilon theophrasti* | Meir et al. (2009) |

For an organic product to be marketed and used by farmers, several processes are required to consider its viability, as shown in Figure 3.

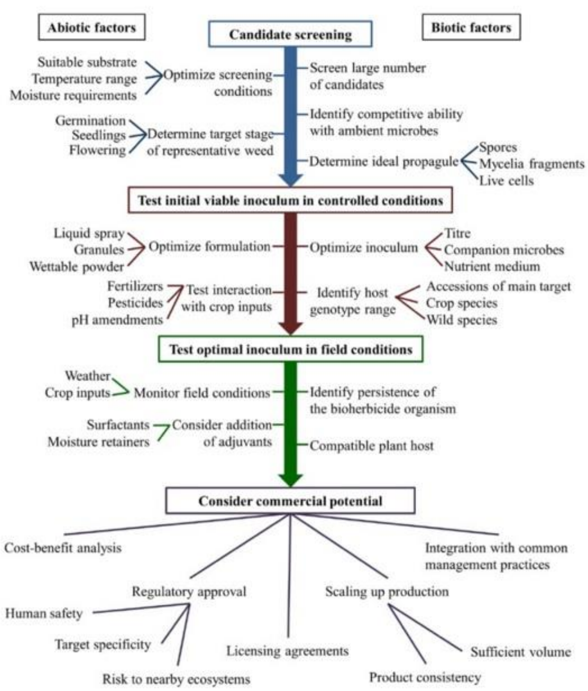


**Figure 3.** Diagram of processes for the production of bioherbicides. Source: Harding and Raizada (2015).

In contemporary agriculture, weed biological control may have an important role in weed control situations that are problematic to other control methods or even for use in an integrated weed management. It is noted that normally the elimination of a single weed species in a weed community can only make room for development of other species. However, if the weed eliminated is difficult to control such as horseweed (*Conyza* spp.) or sourgrass (*Digitaria insularis*), for example, its suppression from the crop becomes highly significant and positive.

## Final Remarks

Synthetic herbicides have been widely used to control weeds. However, the emergence of resistant or tolerant populations has generated environmental problems, contamination of applicators and food, and harmful effects to soil organisms, among other reasons, which has led to the search for new management strategies.

In this sense, formulating herbicides with new sites of action is very important, considering that the appearance of weeds with resistance to conventional herbicides has increased very much in recent years. Besides the problems with resistance, it is clear that the success of the agricultural activity is directly related to the use of efficient methods in weed management.

The study of toxins produced by pathogens and plants is fairly new and is a chance for the development of commercial herbicides that are effective in weed control and/or less damaging to agricultural and environmental cultures, allowing the development of sustainable agricultural systems.

The adoption of new forms of weed management and the integration of cultural, physical, mechanical, biological and preventive control methods are important to replace or even to reduce the use of chemical control, since this has caused many problems to the environment and to man, be these problems caused by misuse of this technique or inherent to the method itself.

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