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Bio-herbicides: An Eco-friendly Approach for Weed Management

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Introduction

Weed plant species have a considerable negative impact on agricultural crop output, and managing them is a serious challenge for the agricultural sector. These plants can quickly absorb scarce natural resources including water, light, soil nutrients, and space. They can multiply quicker than cultivated plants due to characteristics such as a deep root system, drought and frost resilience, and high nutrient utilization efficiency. Furthermore, weeds can leak allelopathic compounds into the soil, which promotes the growth of pests and crop pathogens. These features make them competitive with arable crops, typically resulting in a decrease in agricultural output while increasing cultivation costs. Unfortunately, the excessive and frequently improper use of chemical herbicides has resulted in a variety of negative side effects, including plant resistance, soil and groundwater contamination, and harm to non-target organisms. There is a need requirement for suitable alternatives of chemical herbicides. Bio-herbicides are an eco-friendly alternative to chemical herbicides, reducing environmental impact and health risk.

Bio-herbicides are substances that suppress weed populations by the use of bio-organisms like as fungi, bacteria, viruses and plant-based products including plant extract and essential oils and natural metabolites. Bio-herbicides are a new strategy for addressing the inadequacies of traditional conventional herbicides. The bio-herbicide inhibit of physiological activities like nutrient uptake, photosynthesis etc and disrupt cellular functions like cell wall and cell membrane, hormone and toxic production etc. Microbes can overcome weed plant resistance and infect the target plant due to their virulence factors. There are two major groups of virulence factors. The first category contains enzymes that break down cell walls, lipid membranes, and weed proteins. Amylases, pectinases, cellulases, enzymes that change lignin, proteases, peptidases, and phospholipases are all members of this class. The second group of

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virulence factors consists of peptides and secondary metabolites with phytotoxic characteristics that disrupt weed physiological and metabolic systems. Different types of formulation have been developed to enhance the shelf life of different bio-herbicides for successful commercialization.

Fungal pathogens as bio-herbicides (Mycoherbicides)

Many fungi have been shown to exhibit broad spectrum weed control ranges. Fungal pathogens are the most promising alternative of synthetic chemical herbicides for weed management systems. Fungal pathogens weed control is based on their phytotoxic metabolites. These metabolites inhibit the plant pathways and toxic to weed plant cells. *Alternaria, Phytophthora, Colletotrichum, Fusarium, Pseudocercospora, Cochliobolus, Ascochyta, Drechslera, Phoma, Phyllostictica, Pyrenophora, Septoria, Stagonospora, Amphobotrys, Myrothecium* are the most common fungal pathogens for the bio-control of weeds. Fungi also suppress weed growth and development by creating specific types of secondary metabolites. Fungal phytotoxins attack plants, disrupt the proper functioning of their systems, and ultimately kill their hosts. Soil-borne fungi are potentially important bio-herbicide candidates because they may be applied directly to soils to reduce weed populations through the decay of seeds before emergence or kill seedlings shortly after emergence. Some important commercially available mycoherbicides are listed in table-1.

Table 1: Commercial use of mycoherbicides, target weed and ecosystems

Bio-control agent/Fungal Pathogens	Target weeds	Formulation/Carrier	Ecosystem
Colletotrichum gloesporiodes f. sp. aeschynomene	Northern joint vetch (*Aeschynomene virginica*)	Collego, LockDown	Rice, soybean
Colletotrichum gloesporiodes f. sp. malvae	Roundleaf mallow (*Malva pusilla*)	Biomal, Mallet	Flax, lentils, horticultural crops
Colletotrichum gloesporiodes f. sp. cuscutae	Dodders (*Cuscuta* spp.)	Product in use in China “Lubao 1-S22”	Soybean
Colletotrichum acutatum f. sp. hakeae	Hakea (*Hakea sericea*)	Hakatak- available - South African market	Mountain meadows

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Colletotrichum truncatum	Hemp sesbania (*Sesbania exaltata*)	Coltru	Soybean, cotton, rice
Colletotrichum coccodes	Velvetleaf (*Abutilon theophrasti*)	Velgo	Maize, soybean
Phytophthora palmivora	Strangler or milkweed vine (*Morrenia odorata*)	DeVine	Citrus groves
Alternaria cassia	Sicklepod (*Cassia obtusifolia*)	CASST	Soybean
Alternaria destruans	Dodders	Smolder	Cranberry
Puccinia candiculata	Yellow nutsedge (*Cyperus esculentus*)	Dr. BioSedge	Horticultural crops
Puccinia thlaspeos	Dyer's woad (*Isatis tinctoria*)	Woad Warrior	Rangelands, non-crop areas
Chondrostereum pupureum	Black cherry (*Prunus seratina*), Red alder (*Alnus rubra*), *Populus* spp.	Biochon, Chontrol-Canada	Forest, rangelands
Cylindrobasidium	*Acacia* spp.	Stumpout-South Africa	Forest, rangelands
Nectria ditissim	Red alder (*Alnus rubra*)	PFC-Alderkill- use in Canada	Forest
Phoma macrostoma	Various broadleaf weeds	Bio-Phoma	Pastures, grasslands
Lasiodiplodia, Macrophomina, Neoscytalidium combination	Parkinsonia, Jerusalem thorn (*Parkinsonia aculata*)	Di-Bak- use in Australia	Grassland, rangeland riparian areas
Sclerotinia minor	Dandelion (*Taraxacum officinale*)	Sarritor- Canada	Lawns, recreational areas
Fusarium oxysporum f. sp. orthoceras and *F. oxysporum*	Broomrape (*Orobanche cumana* and *O. crenata*)	"FOO"- Formulation trials, commercialization underway-Egypt	Sunflower, faba bean, tomato

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Trichoderma koningiopsis	Wild poinsettia (*Euphorbia heterophylla*)	Field evaluation-Brazil	Row crops and noncrop areas

Bacterial pathogens as bio-herbicides

Many bacteria have been proved as potential bio-control agent for weeds. Plant pathogenic bacteria, including *Xanthomonas campestris pv poae* (Xcp) and *Pseudomonas syringae pv tagetis* (Pst), were developed as foliar-applied bio-herbicides for the control of annual bluegrass (*Poa annua*) and Asteraceae (composite) weeds, respectively. Two highly effective non-pathogenic isolates, *P. fluorescens* D7 and *P. fluorescens* ACK55 have been commercialized, applied as liquid suspensions or in encapsulated clay for use in cereal crops and rangelands (Table 2).

Table 2: Different bacterial target weed and ecosystems

Bio-control agent/Bacterial Pathogens	Target weeds	Formulation/Carrier	Ecosystem
Xanthomonas campestris pv. poae	Annual bluegrass (*Poa annua*)	Camperico- Used in Japan	Turf, lawns
Pseudomonas syringae pv. phaseolicola	Kudzu (*Pueraria lobata*)	Formulated, field tested	Non cropland, pastures
P. syringae pv. tagetis	Asteraceae weeds (composites)	Formulated, field tested	Maize, soybean, pastures
Ralstonia solanacearum	Tropical soda apple (*Solanum viarum*)	Formulated, field tested	Pastures, noncrop areas
Pseudomonas fluorescens D7	Downy brome (*Bromus tectorum*)	Commercialized- "D7"	Cereal crops
Pseudomonas fluorescens ACK55	Downy brome (*Bromus tectorum*) Jointed goatgrass (*Aegilops cylindrica*), Medusahead (*Taeniatherum caput-medusae*)	Commercialized- "Battalion Pro"	Cereal crops, rangelands

Lactobacillus spp. strains; *Cremoris* sp.	Clovers (*Trifolium* spp.), birdsfoot trefoil, (*Lotus corniculatus*)	Commercialized- "Organo-Sol," "Kona," "Bioprotec"- Canada	Lawns, turf

Viruses as bio-herbicides

Viruses can also be employed as bio-herbicides to suppress certain weeds, however due to limitations, they are ineffective as fungal pathogens. Viruses have lots of genetic variability and are not target specific. The tobacco mild green mosaic virus (TMGMV) is a patented bio-herbicide used to control tropical soda apple (*Solanum viarum*), an invasive perennial weed found in pastures and non-cropland areas in the south-eastern and mid-southern United States (table 3).

Table 3: Viral pathogens, targeted weed and ecosystems

Bio-control agent/Bacterial Pathogens	Target weeds	Formulation/Carrier	Ecosystem
Tobacco mild green tobamovirus	Tropical soda apple	Commercialized- "SolviNix"	Pastures, non-crop areas

Natural products as bio-herbicides

Many plant-based products can also be used as natural weed control agents. Plants produce secondary metabolites or other photochemicals that hinder seed germination and other growth activities. Plant products can be used as weed control agents in three forms i.e. plant extracts, essential oils, and allelochemicals. These three plant components have been used as potential bio-herbicides for several decades. The major method of action of plant-based products is to impede the germination of weeds and reduce plant development. Plant extracts contain many elements such as peptides, secondary metabolites, alkaloids, terpenoids and tetraterpenoids etc. These compounds, grouped as "biochemical bio-herbicides". Table 4 shows examples of natural compounds with bio-herbicidal action, including those commercialized or in development for practical application.

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Table 4: Representative natural products as bio-herbicides

Bio-herbicide	Target weeds	Mode of action/Comments
	Plant Extracts	
Corn gluten meal extract (hydrolysate)	Broad-spectrum PRE control of weeds in turf	Complex of phytotoxic dipeptides
Mustard seed meal extract	Green foxtail (*Setaria viridis*); Powell amaranth (*Amaranthus powellii*)	Sinalbin (4-hydroxybenzyl glucosinolate) active substance in extract
Rapeseed oil	Broad spectrum weeds; potato vine desiccant	Commercialized as 'Beloukha'-Europe
Dried distillers grains extracts (DDGSs)	Annual bluegrass (*Poa annua*); common chickweed (*Stelaria media*)	Methanolic extracts of DDGS
Saturated fatty acids, i.e., Pelargonic acid	Broad-spectrum annual weeds	Geranium (*Pelargonium roseum*) leaf extract; many preparations marketed
Aglaia odorata leaf extract-PORGANIC(™)	Inhibited root and shoot growth of garden cress (*Lepidum sativum*), lettuce (*Lactuca sativa*), alfalfa (*Medicago sativa*), timothy (*Phleum pratense*), ryegrass (*Lolium multiflorum*) and *Echinochloa crus-galli*	Inhibit growth of weed plant
Ammi visnaga (L.) Lam. Khellin and Visnagin- plant extract	lettuce (*Lactuca sativa*) and duckweed (*Lemna paucicostata*) velvetleaf (*Abutilon theophrasti*), crabgrass (*Digitaria sanguinalis*)	Inhibit seed germination, photosynthesis, and cellular activities.

Lichen (*Cladonia verticillaris*)- Phenolics extracts	Lettuce	Change the cellular structure of leaves and roots of lettuce seedlings
Essential Oils		
Manuka oil	Crabgrass (*Digitaria* spp.) and broad-spectrum of dicotyledonous weeds	Distilled from plant parts of manuka tree (*Leptospermum scoparium*)
Artemisia oil	Coffee senna (*Cassia occidentalis*), Ageratum (*Ageratum conyzoides*); Barnyardgrass	Volatile oil (1,8 ceneole) of wormwood or sage brush (*Artemisia scoparia*)
Savory oil	Redroot pigweed (*Amaranthus retroflexus*), Common lambsquarters (*Chenopodium album*)	Carvacrol and terpinene oils; prepared oil/water nanoemulsion for application
Monoterpene cineoles	Broad-spectrum	Numerous aromatic herbs, i.e., Eucalyptus, Salvia
Eucalypt (*Eucalyptus nicholii*), Rosemary (*Rosmarinus officinalis* L.), Lawson cypress (*Chamaecyparis lawsoniana*) and White cedar (*Thuja occidentalis*) plants	Amaranth, Purslane and Knapweed	Amaranth, Purslane and Knapwee germination inhibitors species
Allelochemical-based		
Sorgoleone	Barnyard grass (*Echinochloa crus-galli*), velvetleaf (*Abutilon theophrasti*), Bent grass (*Agrostis stolonifera*)	Exuded from roots of sorghum (*Sorghum bicolor*)

Rice hull extracts	Barnyard grass	Inhibition of germination, seedling growth, and weight in barnyard grass
Black walnut (*Juglans nigra*) from walnut- Plant extract	Horseweed (*Conyza canadensis*) and hairy fleabane (*Conyza bonariensis*)	Inhibit growth of horse weed (*Conyza canadensis*) and hairy fleabane (*Conyza bonariensis*) act as a pre- and post-emergent bio-herbicide- Commercialized as "NaturCur".
Rice var. OM5930 shoot þ root extracts	Barnyardgrass, fimbry (*Fimbristylis miliacea*), red sprangletop (*Leptochloa chinensis*)	Crystalized formulation of aqueous extracts; suppress seedling growth
Barley (*Hordeum vulgare*) extract	Filamentous algae in aquatic environments	Extract released during decomposition in water
Wild tomato (*Solanum habrochaites*) extracts	Broad-spectrum weeds	Burndown (knockdown) use; commercialized as "WeedLock" in Malaysia

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