Allelopathy in pigweed (a review)

Marcelo Claro de Souza^{1*}, Leonardo Bianco de Carvalho², Pedro Luis da Costa Aguiar Alves³ and Paulo Roberto Fidelis Giancotti⁴

¹Doctorate student at the Institute of Biosciences of the São Paulo State University, Rio Claro, Brazil, marcelo_claro@yahoo.com.br. ²Postdoc at Faculty of Agrarian and Veterinarian Sciences of the São Paulo State University, Jaboticabal, Brazil, agrolbcarvalho@gmail.com. ³Professor at Faculty of Agrarian and Veterinarian Sciences of the São Paulo State University, Jaboticabal, Brazil, plalves@fcav.unesp.br. ⁴Master student at Faculty of Agrarian and Veterinarian Sciences of the São Paulo State University, Jaboticabal, Brazil, paulogiancotti@gmail.com.

*Author for correspondence

Amaranthus spp. are plants with proven allelopathic potential. The release of allelochemicals from *Amaranthus* spp. in the environment can influence seed germination, photosynthesis rate, reduce growth and, consequently, the productivity of various plant species. Among the species with allelopathic potential are *Amaranthus blitoides*, *Amaranthus gracilis*, *Amaranthus hybridus*, *Amaranthus palmeri*, *Amaranthus retroflexus*, *Amaranthus spinosus* and *Amaranthus viridis*, with *A. retroflexus* being the most studied species and *A. spinosus* being the species with the greatest allelopathic potential. Due to the large quantities of allelochemicals produced by *Amaranthus* spp. these plants stand out as future suppliers of chemical molecules for bioherbicides and semisynthetic herbicides.

Keywords: *Amaranthus*, allelopathic potential, literature review.

Introduction

The term allelopathy was coined by Hans Molish in 1937, a concept discussed for some time, with divergence among researchers since the emergence of this science. For this reason, in 1996, the International Society of Allelopathy defined the term as any process involving secondary metabolites produced by plants, microorganisms, viruses and fungi that influence the growth and the development of biological and agricultural systems (Allelopathy Journal 2009).

Among the plants with proven allelopathic potential one finds several species of the genus *Amaranthus*, commonly known as pigweed and amaranth. The region of origin of the majority of species of this genus is Tropical America, where a large population of defined species are found as well as interspecific crossings (Kissmann and Groth 1999), which originate through natural hybridizations (Trucker and Sauer 1958).

The genus *Amaranthus* is represented by approximately 60 species (Uphof 1968, Willis et al. 1973, Singh et al. 1983, Wiersema and Leon 1999), widely distributed in tropical, subtropical and temperate regions. At least 20 species of pigweed are important as weeds, some as ornamental plants and others are utilized as food, leaf vegetables and cereals (Kissmann and Groth 1999).

In Brazil, circa 10 species occur as infesting plants in agroecosystems (Kissmann and Groth 1999). According to Lorenzi (2000) and Carvalho et al. (2006), the most common species are *Amaranthus deflexus*, *Amaranthus hybridus* var. *paniculatus*, *Amaranthus hybridus* var. *patulus*, *Amaranthus lividus*, *Amaranthus retroflexus*, *Amaranthus spinosus* and *Amaranthus viridis*. Other species also stand out as serious problems around the world, such as *Amaranthus blitoides* (Suma 2002), *Amaranthus blitum* (Costea and Tardif 2007), *Amaranthus palmeri* (Kendig 2009),

Amaranthus powellii, *Amaranthus rudis* and *Amaranthus albus* (Ortiz Ribbing and Williams 2006) (Table 1).

Pigweed plants are also important as human and animal food, besides ornamentation, which have been utilized since ancient times by primitive inhabitants of Tropical and Sub-tropical America. Some species were domesticated and are being genetically improved for grain and leaf production (Suma 2002).

Pigweeds, as grain culture, are cultivated in America, India, parts of China and South-west Siberia (Suma 2002), while, according to Uphof (1968), in regions of India irrigation was utilized in the cultivation of this morphotype. The grain productivity, the flavor and the nutritional value are similar to corn in other grain cultures (Suma 2002). The commercial production in Brazil was initiated as an alternative off-season crop in no-till farming, in the hope that the grain could be utilized by the food and feed industries. The whole plant, as forage, can be integrated with animal feed farming.

Discussion

Secondary metabolites

The metabolism of plant cells can be divided in primary and secondary. Primary metabolism is the complex of metabolic processes that perform an essential function in the plant, such as photosynthesis, respiration and transport of solutes, where the components involved in these processes are universally distributed in plants. On the other hand, secondary metabolism gives rise to compounds that are not universal, since they are not essential for all plants (Castro et al. 2005).

There are three groups of secondary metabolites: terpenes, phenolic compounds and alkaloids. The terpenes are produced from mevalonic acid or

Table 1. Distribution of the main species of *Amaranthus* spp.

Scientific Name	Distribution
<i>Amarantus albus</i> L	Canada, USA
<i>A. blitoides</i> Watson	USA
<i>A. blitum</i> L., Syn <i>A. lividus</i> L	Africa, Asia (India, Malasia), Europe
<i>A. caudatus</i> L. Syn <i>A. edulis</i> Speg. <i>A. leucoparcus</i> Watson, <i>A. mantegazzianus</i> Pass	South of Andean America
<i>A. cruentus</i> L. Syn <i>A. hybridus</i> subsp. <i>Cruentus</i> (L.) Thell. <i>A. paniculatus</i> L	Central America, Mexico
<i>A. deflexus</i> L.	América do Sul, Brasil
<i>A. dubius</i> C. Mart. Ex Thell	Mexico
<i>A. edulis</i> Speg. = <i>A. caudatus</i>	China
<i>A. gangeticus</i> L. = <i>A. tricolor</i> L.	Tropics, India, China, Malasia, Japão
<i>A. graecizans</i> L.	Africa, Temperate Asia, India, Europe
<i>A. grandiflours</i> Black	Australia
<i>A. hybridus</i>	USA, South America, India
<i>A. hybridus</i> Subsp. <i>Cruentus</i> (L.) Thell = <i>A. cruentus</i> L., <i>A. chlorostachyus</i> Thell	Mexico
<i>A. hybridus</i> var. <i>erythrostachys</i> Moq.	
<i>A. hybridus</i> var. <i>paniculatus</i> , <i>A. hybridus</i> var. <i>patulus</i>	Brazil
<i>A. hypochondricus</i> L. Syn. <i>A. hybridus</i> var. <i>erythrostachys</i>	Mexico, Asia, Africa
<i>A. leucocarpus</i> Watson = <i>A. caudatus</i>	Mexico, Guatemala, Central America
<i>A. lividus</i> L. = <i>A. blitum</i> L.	Brazil
<i>A. macrocarpus</i> Benth	Australia
<i>A. mangostanus</i> L.	India, Japan
<i>A. mantegazzianus</i> Pass = <i>A. caudatus</i> L. <i>A. palmeri</i> Watson	North America
<i>A. paniculatus</i> L. = <i>A. cruentus</i>	
<i>A. powellii</i> Watson	Canada, USA, South America
<i>A. quitensis</i> Kunth	Brazil, South America
<i>A. retroflexus</i> L.	Brazil, Canada, USA, Mexico
<i>A. rudis</i> , <i>A. spinosus</i> L.	Brazil, Tropics, Sub-tropics
<i>A. thunbergii</i> Moq	Africa
<i>A. tricolor</i> L. Syn <i>A. gangeticus</i> L. <i>A. polygamus</i> L., <i>A. oleraceus</i> Wild	India, China
<i>A. viridis</i>	Brazil, Tropics

Source: Suma et al. (2002)

pyruvate and 3-phosphoglycerate. The phenolic components derive from shikimic acid or mevalonic acid. The alkaloids derive from de aromatic amino acids, which are derived from shikimic acid, and also from aliphatic amino acids (Castro et al., 2005).

Plant secondary metabolites are responsible for characteristics such as flavor, odor, color, and aroma, acting in the attraction of polinators and dispersion of fruits, whereas some of these components are potentially toxic to animals and microorganisms, acting as antibiotic substances, besides exhibiting allelopathic characteristic (Larcher 2000).

Allelopathic potential of *Amaranthus* spp.

In Agrarian Sciences, the secondary metabolites

with allelopathic potential are usually referred to as allelochemicals, however, in the literature synonymous terms are found such as allelotoxins, phytoinhibitors, phytotoxins, among others. These compounds are produced naturally by plants and their principal ecological function is the protection against insect pests and diseases (Castro et al. 2005). In addition, the allelochemicals are an important defense for certain plants against the interference of other plants of the same or different species, which can affect their growth and development (Larcher 2000).

When a plant with allelopathic potential is a weed species, such as the case of *Amaranthus* spp., it may cause problems in agricultural production, depending on the adopted management in the production area.

Allelochemicals of *Amaranthus* spp. can influence the germination of seeds of various cultures, affect their photosynthetic rate, reduce their growth and, consequently, their productivity (Suma 2002), as can be observed in investigations reported in the literature and described below.

The allelochemicals present in pigweed plants when released in the environment influence the germination and the growth of seedlings of various species (Gass and Bohm 1971, Chatterji 1975, Einhellig and Rasmussen 1978). In field studies, residues of *A. retroflexus* reduced the productivity of *Zea mays* (corn) by 15 to 20%, while the allelochemicals present in the residue of the plant interfered in the photosynthesis, in the accumulation of leaf biomass and in grain productivity (Bhowmik and Doll 1982, Bradow and Connick 1987, Bradow and Connick 1987). The decomposition of the residues of the aerial part of *A. retroflexus* and the pre-infestation of the soil diminished the growth of *Nicotiana tabacum* (tobacco). After transplantation of *N. tabacum* seedlings the interference continued for a period greater than 3-4 weeks, diminishing plant height, fresh mass, number of leaves and productivity when compared to the control non-infested culture (Lolas 1986). Residues of the aerial part of *A. retroflexus* and *A. blitoides* incorporated in the soil reduced the height, the production of grain and the amount of straw of *Triticum aestivum* (wheat) and caused reductions in the productivity of *Hordeum vulgare* (barley) in the order of 43 and 23%, respectively for each weed species (Qasem 1994, Qasem 1995a).

In another experiment, the fresh matter of the following four weed plant species, *A. spinosus*, *Cyperus rotundus* (nutsedge), *Echinochloa colonum* (junglerice) and *Imperata cylindrica* (cogongrass) was incorporated in the soil in *Oryza sativa* (rice) culture at 0.5, 0.75 and 1.0 kg.m⁻². The biomass incorporated in the soil reduced the rice productivity in the following order: *I. cylindrica* > *C. rotundus* > *E. colonum* > *A. spinosus* (Gaffar et al. 1998). Burned residues of *A. viridis* diminished the growth and the productivity of *Pennisetum americanum* (millet) (Sighal et al. 1981).

Residues of *A. palmeri* incorporated in the soil inhibited the growth of carrot and onion by 68% and the phytotoxicity persisted for 11 to 16 weeks after the incorporation (Bradow and Connick 1987, Mengues 1987). Residue concentration of 800 and 1600 ppm in soils severely inhibited root growth of *Sorghum vulgare* (sorghum). The growth of seedlings of *S. vulgare* was more drastically inhibited by leaf extracts than stem and root extracts (Mengues 1988). *A. palmeri* releases allelochemicals to the environment by decomposition and volatilization of its residues. Leachable components from various parts of *A. spinosus* plants supplement germination and growth of seedlings of various cultures (Suma 1998, Ambika and Suma 1999). Bradow and Connick Jr (1987) isolated allelochemicals from *A. palmeri* with potential to cause growth inhibition in cultivated as well as feral plants. In addition to *A. palmeri* other pigweed species can produce and eliminate allelochemicals from the environment that could be absorbed by other plants as

reported for *Lemna minor* (duckweed), *S. bicolor*, *G. hirsutum*, *H. annuus*, *N. tabacum* and *H. vulgare* (Gass and Bohm 1971, Ambika and Suma 1999), while often these residues can inhibit the growth of plants of the same species or cultivated varieties as observed with *Allium cepa* (onion) and *Daucus carota* (carrot) (Bradow and Connick 1987, Mengues 1987, Mengues 1988).

Incorporation of dry residues of the aerial part of *A. retroflexus* reduced the germination of *Brassica oleracea* (cabbage), *D. carota*, *Brassica oleracea* var. *brotrytis* (cauliflower) and *Solanum melongena* (eggplant), as well as *Capsicum annuum* (bellpepper), *Lycopersicon lycopersici* (tomato), *Cucumis sativus* (cucumber) and *Cucurbita ovifera* (squash). The inhibitory effects to transplanted *C. ovifera* and *L. lycopersici* were overcome with supplementation of nutrients (Qasem 1995a). Residues from the aerial part of *A. retroflexus* reduced the germination of *Helianthus annuus* (sunflower) and *Glycine max* (soybean) by 82 and 96%, respectively (Béres and Cazinczi 2000). In greenhouse studies, aqueous extracts of dry residues of *A. retroflexus* inhibited root elongation in *Z. mays* and the elongation of hypocotyl in *G. max*. The residue incorporated in the soil significantly reduced the growth of seedlings, foliage area, the weight ratio of the leaves and the assimilation of nitrogen and phosphorous in *Z. mays* and *G. max* until 28 days after planting (Bhowmik and Doll 1982, Bradow and Connick 1987, Bradow and Connick 1987). Residues of the aerial part of *A. retroflexus* and *A. blitoides* incorporated in the soil inhibited the germination of *T. aestivum*, retarded the emergence and reduced the growth of *H. vulgare* seedlings. The inhibitory effect and the concentration of residues was dependent on the part of the plant, with roots being more sensitive than the aerial part (Qasem 1994, Qasem 1995b).

Extract of leaves and inflorescence of *A. spinosus* drastically reduced the vegetative and reproductive phases of *Sinapis alba* (mustard) and *T. aestivum* (Datta and Bandyopadhyay 1981). Leached components of *A. spinosus* showed strong allelopathic effect over the growth and establishment of *Parthenium hysterophorus* (congress weed) (Chikkalingaiah and Mahadevappa 1998). Leaves and whole plant extract affected the germination, production of dry matter and vigor of seedlings of *Boerhaavia diffusa* (hog weed or pig weed) at seven days. When applied to older plants, the effect was less harmful.

Marques (1992) reported that the emergence velocity index of *Gossypium hirsutum* (cotton) was stimulated when small quantities of residue of *A. viridis* were incorporated in amended AQd soils and in LR soils without amendments. The decomposition of larger quantities of residue showed inhibitory effect on germination and growth of *G. hirsutum*, which were more pronounced in sandy soils. The allelopathic substances affected the absorption of nitrogen and water, promoted reduction of transpiration and affected the accumulation of dry matter by the plants. These factors were more pronounced in sandy soils, which,

according to the author, further increases the management difficulties in this type of soil.

Santos et al. (2001) concluded that dead crop cover of coffee and rice husks between rows of coffee plantation favored inhibition of germination or stimulation of growth of *A. viridis*, furthermore, dead crop cover of rice husks shows greater inhibition in the level of infestation of *A. viridis* than coffee husks. Dead crop cover of coffee husks favors greater stimulation to the growth of the plants and to the production of aerial part dry matter of *A. viridis* than rice husks. Coffee productivity increases when dead crop cover of coffee husks are applied or rice husks are incorporated in the soil.

Santos et al. (2002), concluded that aqueous extract of rice husks favors greater inhibition in velocity and percentage of emergence of slender amaranth than extract of coffee husks, furthermore, aqueous extract of coffee husks cause greater stimulation in the growth of the plant and in the production of dry matter of slender amaranth than rice husk extract.

Erasmio et al. (2004) showed that species such as *Crotalaria spectabilis* (showy rattlebox), *Sorghum bicolor* (hybrid sorghum), *Crotalaria ochroleuca* (slender leaf rattlebox rattleweed), *Mucuna aterrima* (black cowitch) and *Mucuna pruriens* (grey cowitch), utilized as green fertilizer, significantly reduced the number and the weight of dry matter of *A. spinosus* and other weed plant population.

Bhowmik and Doll (1982), and Bradow and Connick (1987) reported that aqueous extracts of dry residues of *A. retroflexus* inhibited the elongation of the radicle in *Z. mays* and the elongation of the hypocotyl in *G. max*. Leaf and aerial part extracts of *A. retroflexus* promoted greater inhibition in the germination, vigor and weight of *Medicago sativa* (alfalfa) seedlings than root extracts (Chung et al. 1994, Chung and Miller 1995). The inhibitor compounds present in root exudates inhibited the root dry matter of *Beta vulgaris* var. *altissima* (sugarbeet), but increased the level of sugar in the roots (Ivashchenko 1993).

Aqueous extracts of the aerial part of *A. retroflexus* strongly inhibited the germination of *H. annuus* and *G. max* (Muminoc 1990, Béres and Cazinczi 2000). Extracts of the aerial part dry matter of *A. retroflexus* inhibited the germination of *B. oleracea* and *S. melongena* and reduced the dry weight of the aerial part of *B. oleracea*, *S. melongena*, *D. carota* and *C. annuum* (Qasem 1995a). Aqueous extracts of the aerial part and roots of *A. retroflexus* inhibited the germination and growth of seedlings (length, weight and vigor of seedlings) of *M. sativa* (Chung et al. 1994, Chung and Miller 1995). Extracts of roots, aerial part and whole plant of various pigweed species reduced the germination and growth of seedlings of *S. vulgaris*, *Eleusine coracana* (finger millet), *P. americanum*, *G. hirsutum*, *Vigna radiata* (green mung bean) e *Vigna mungo* (black mung bean) (Velu et al. 1990). Aqueous extracts of dry leaves of *Amaranthus tricolor* retarded the germination and inhibited root and aerial part growth of *S. bicolor* seedlings. The inhibitory effect was directly related to the concentration of the extract

(Chatterji 1975, Mohnot and Soni 1979). Aqueous extract of leaves of *A. viridis* inhibited the germination of seeds of *P. americanum* and the growth of seedlings of *P. americanum* and *Sesamum indicum* (sesame). The order of inhibition by aerial parts of seedlings of *S. indicum* was fruit > stem > leaf > root > seed and in seedlings of *P. americanum* was leaf > root > stem > seed > fruit (Sigal et al. 1981). Extracts of roots and aerial part of *A. retroflexus*, *A. blitoides* and *Amaranthus gracilis* reduced the germination, the length of the hypocotyl and the roots and the dry weight of roots of seedlings of *H. vulgare* and *Triticum durum*. The inhibitory effect was dependent on the concentration. Fresh extracts were more toxic than extracts of dry plants and extracts of the aerial part were more harmful than the roots (Qasem 1995a).

Aqueous extracts of seeds of *A. retroflexus* inhibited the germination of vegetables such as *L. lycopersici*, *C. annuum* and *D. carota* and reduced the growth of seedlings of *T. aestivum* (Ognjaconvic et al. 1995). The effect of ontogenic extract of various parts of *A. retroflexus* embryo at concentrations of 0-1000 ppm over the germination, growth of roots and aerial part of *Setaria verticillata* (hooked bristlegrass), *S. alba*, *Phaseolus vulgaris* (kidney bean) and *T. aestivum* showed that the inhibitory or the stimulatory effect depends on the species tested and on the extract concentration (Athanasova 1996).

Amaranthus spinosus exhibits allelopathic effect over the growth of some cultures (Suma 1998). Leached components of the parts of the plant inhibited the growth of seedlings of *E. coracana*, *Cajanus cajan* (pigeonpea), *Trigonella foenum-graecum* (sicklefruit fenugreek) and *Cyamopsis tetragonoloba* (guar). The maximum inhibition was caused by leached components of the leaves and the minimum by leached components from the roots. The aqueous leached components from different parts of *A. spinosus* of three locations in Bangalore, India, inhibited the germination and the growth of seedlings of *T. foenum-graecum* and *C. cajan* (Suma 1998). The total phenolic acids was the highest in the leaves, followed by stems, inflorescence and the lowest in the roots. The quantity of phenolic acids was the greatest in plants growing in soils polluted with domestic, industrial and vehicle residues (Ambika and Suma 1999). Even the soil rhizosphere collected in these regions promoted inhibitory effects in the growth of the test plants. The accumulation of root dry matter was more affected indicating lower translocation of photoassimilates to those parts.

Leucaena leucocephala (white leadtree) plant extract showed inhibitory effects over germination and initial growth of *A. hybridus* (Pires et al. 2001). Extracts from the aerial part, roots and whole plant of various species of pigweed increased the germination and vigor of *Arachis hypogaea* (peanut) seedlings, as well as *Rhizobium* spp. (Glosh et al. 200) and did not show significant effect in *Z. mays*, *C. cajan* and *S. indicum* (Velu et al. 1990). Low concentrations of extract of the aerial part of pigweed species (*A. blitoides*, *A. gracilis* and *A. retroflexus*) promoted the growth of the aerial part of *T. aestivum* (Qasem 1995b). Extracts of *A.*

retroflexus increased the germination of *H. annuus* by 7.9% (Muminoc 1990). The inhibitory and stimulatory effects of pigweed species are dependent on the part of the plant and on the concentration (Qasem 1995a, Qasem 1994, Qasem 1995b, Athanassova 1996). Residues of *A. gracilis* stimulated increase in plant height and in productivity of *T. aestivum* and *H. vulgare* (Qasem 1995a, Qasem 1994, Qasem 1995b).

Alves (Alves 1984) reported greater inhibitory allelopathic activity over the growth of seedlings of *C. sativus* by *A. retroflexus* plants than *A. viridis* and *A. hybridus* var. *paniculatus*. This activity was maintained when residues were incorporated in the soil, being proportional to the quantity incorporated, but losing its effect with the progression of decomposition. The parts of the plants that showed greater inhibitory capacity were the leaves followed by inflorescence and roots. On the other hand, extrats of the plant, when sprayed over the seeds and seedlings of *C. sativus*, did not achieve a significant influence in the growth of the same plants.

Aqueous extracts of various species of medicinal plants significantly reduced the germination and negatively affected the length of the hypocotyl and the roots of *A. retroflexus*, with the level of inhibition dependent on the species (Qasem 2002). Extracts of *Alhaji maurorum*, *Capparis spinosa*, *Citrullus colocynthis*, *Lavanda officinalis*, *Origanum syriacum*, *Rhus coriaria*, *Rosmarinus officinalis* and *Teucrium polium* were more prejudicial, completely inhibiting the germination of *A. retroflexus* seeds. In general, leaf extracts were inhibitorier than stems in the germination as well as in the growth, although, leaf extracts of *L. officinalis* stems were extremely toxic and completely inhibited the germination of *A. retroflexus*.

Leached components of *L. officinalis* and *R. officinalis* completely inhibited the germination of *A. retroflexus*, while volatilized components from these plants were extremely toxic to the weed plant (Qasem 2002). Residues of *R. officinalis* plants were highly toxic to *A. retroflexus* plants, affecting development of the roots, with the intensity of the effect varying as a function of the concentration of the extract. On the other hand, aqueous extracts of the aerial part of *C. spinosa*, applied on the soil, were the most toxic, negatively affecting the germination and the growth of *A. retroflexus*, while extracts of *L. officinalis* inhibited the growth of the aerial part of the weed species.

Allelochemicals

Various allechemicals were isolated and identified in *Amaranthus* spp. plants. according to Suma (1998), the principal allelochemicals present in *A. spinosus* are phenolic acids, alkaloids and sesquiterpene lactones. Through chromatographic separation and ultraviolet analysis, this author observed the presence of 5, 6 and 9 different phenolic acids in roots, inflorescence and leaves of this species, respectively, among them are the are acids p-hydroxybenzoic, ferulic, sinapic, salicylic, chlorogenic, gentisic, vanillic and syringic. Suma (1998) and Ambika and Suma (1999) determined that the quantity of phenolic acids

produced by *A. spinosus* plants was not influenced by the location where the plant developed.

Narwal (1994), Qasem (1995a) and Velu and Ali (1995) observed the presence of alkaloids belonging to the quinolizidine class, steroid and indol in *A. spinosus*. Beyond these compounds, numerous sesquiterpene lactones were found in material leached from *A. spinosus*.

Connick Jr et al. (1987), by means of gas chromatography with mass spectrometry, identified some volatile secondary metabolites with allelopathic potential in seeds, roots and stem of *A. palmeri*, among them are methylketones and alcohols.

Allelochemicals as potential herbicides

Increasingly, the indiscriminate use of synthetic herbicides stimulate an increase in resistance in weed plant, in environmental polution and in potential harm to the health of individuals that come in contact with these products. Thus, natural products obtained from vegetal raw-material offer a large variety of molecules with great structural diversity and biological activity. These biological activities can be express through their herbicidal insecticidal, fungicidal and/or pharmacological properties (Duke and Lyndon 1993, Duke et al. 1998, Ishaaya 2001), with the liberation of the allelopathic compounds by the plants through leaching from the tissue, volatilization, exudation through the roots and decomposition from residues of the plant via physical, chemical or biological processes (Baghestani et al. 1999, Lotina-hennsen et al. 1998, Costa et al. 1999, Inderjit et al. 2006, Karban 2007).

Plants have their own defense mechanism that act through substances that are referred to as allelochemicals, which are actually natural herbicides. The allelochemicals isolated from plants (Baldwin et al. 2006) or microoranims are a potential source for models of new structural types of herbicides, which can be more specific, with new modes of action and greater potential than those presently used in agriculture. Thus, the use of allelochemicals as herbicides, natural or synthetic, is one of the techniques, involving allelopathy, that have been suggested for the control of weed plants (Macias et al. 1999), herbicides with efficiency and specificity.

The reduction of environmental problems and the cost of crop protection are reflected as proprietary parameters in the improvement of food quality. In this context, there is great interest in phytochemical studies to control weed plants, through modified or synthetic natural products that show herbicidal activity and that, different from the herbicides utilized presently, do not provoke contamination of the soil, water and plants; and show low toxicity to different forms of life in the biological scale (Wright et al. 1991, Trebs and Draber 1986, Albores-Velasco et al. 1986). The synthetic herbicides have a large structural variety, with different modes of action and it is increasingly difficult to discover new molecules that serve as model for synthesis of commercial herbicides, and that are benign to other life-forms (Mizutani 1999, Macias et al. 1999, Reigosa and Pedro 2002, Aliotta et al. 1994).

An important aspect in allelopathy research is the identification of allelochemical compounds involved in the plant-plant interactions and their possible mode of action. The isolation and the knowledge of the structure of the compounds of the plants can result in the production of semisynthetic derivatives. Thus, it is of great importance to isolate the active ingredients from the plants and quantify their concentration in the different parts of the plant or in the different types of extracts through appropriate bioassays.

Conclusions

Amaranthus spp. are plants with proven allelopathic potential, which require more studies related to the effects of their allelochemicals over cultivated plants and other weed plants. Isolation and identification of allelochemical compounds from these plants could provide means to minimize their negative effects over the cultures and potentially could provide structural models for the development of bioherbicides or semisynthetic herbicides.

References

- Albores-Velasco M, Lotina-Hennsen B, Zapein A, González G, Migueles L. 1986. Structure-activity relationship studies of dibromo phenolic derivatives as photosynthetic electron chain inhibitors. *Pestic Sci* 17:296-402.
- Aliotta G, Cafiero G, De Feo V, Sacchi R. 1994. Potential Allelochemicals from *Ruta graveolens* L. and their action on radish seeds. *J Chem Ecol* 20: 2761-2775.
- Allelopathy Journal. Welcome to the world of allelopathy. Allelopathy. Available at: <http://www.allelopathy-journal.com/allelopathy.aspx>. Accessed at: Mar. 03 2009.
- Alves PLCA. 1984. Estudo dos efeitos inibitórios de caruru (*Amaranthus retroflexus* L.) sobre a germinação e desenvolvimento de plântulas de pepino (*Cucumis sativus* L.). 64p. Monograph, Degree in Agronomy, São Paulo State University.
- Ambika SR, Suma S. 1999. Influence of pollutants on the allelopathic potencial of *Amaranthus spinosus* L. *Allelop J* 6:45-56.
- Athanassova DP. 1996. Allelopathic effect of *Amaranthus retroflexus* L. on weeds and crops. *J Intern Et Lut Mauv Herb* 1:437-442.
- Baghestani A, Lemieux C, Leroux G, Baziramakenga R. 1999. Determination of allelochemicals in spring cereal cultivars of different competitiveness. *Weed Sci* 47:498-507.
- Baldwin IT, Halitschke R, Paschold A, Von Dahl CC, Preston CA. 2006. Volatile signaling in plant-plant interactions: "talking trees" in the genomics era. *Science* 311:812-815.
- Béres IO, Cazinczi G. 2000. Allelopathic effects of shoot extracts and residues of weeds on field crops. *Allelop J* 7:93-98.
- Bhowmik PC, Doll JD. 1982. Corn and soybean response to allelopathic effects of weed and crop residues. *Agron J* 74:601-606.
- Bhowmik PC, Doll JD. 1984. Allelopathic effects of annual weeds residues on growth and nutrient uptake on corn and soybean. *Agron J* 76:383-388.
- Bradow JM, Connick JR W.J. 1987. Allelochemicals of palmer amaranth (*Amaranthus palmeri* S. Wats.). *J Chem Ecol* 13:185-202.
- Carvalho SJP, Buissa JAR, Nicolai M, Lopez-Ovejero RF, Christoffoleti, PJ. 2006. Differential susceptibility of *Amaranthus* genus weed species to the herbicides trifloxysulfuron-sodium and chlorimuron-ethyl. *Planta Daninha* 24:541-548.
- Castro PRC, Kluge RA, Peres LEP. 2005. Manual de fisiologia vegetal: teoria e prática. Agronômica Ceres: Piracicaba. 650p.
- Chatterji UN. 1975. Some aspects of plant-plant chemical interactions. *Indian J Plant Physiol* 18:91-96.
- Chikkalingaiah GE, Mahadevappa M. 1998. Effect of different plant species and plant leachates on *Parthenium hysterophorus* L. weed. *Crop Res* 15:106-164.
- Chung IM, Kim KJ, Kim KH, 1994. Allelopathic effect of some weed species extracts and residues on alfafa. *Korean J Crop Sci* 39:285-294.
- Chung IM, Miller DA. 1995. Assessment of allelopathic potential of some weed species on alfafa (*Medicago sativa* L.) germination and early seedling growth. *Korean J Crop Sci* 15:121-130.
- Connick Jr WJ, Bradow JM, Legendre MG, Vail SL, Menges RM. 1987. Identification of volatile allelochemicals from *Amaranthus palmeri* S. Wats. *J Chem Ecol* 13:463-472.
- Costa AV, Barbosa LCA, Demuner AJ, Silva AA. 1999. Synthesis and Herbicidal Activity of 2 α ,4 α -Dimethyl-8-oxabicyclo[3.2.1]oct-6-en-3-one Derivatives. *J Agric Food Chem* 47:4807-4814.
- Costea M, Tardif FJ. The biology of Canadian weeds. 126. *Amaranthus albus* L., *A. blitoides* S. Watson, *A. blitum* L. Available at: http://www.wlu.ca/documents/7485/published_paper.pdf. Access at 28/04/2007.
- Datta SC, Bandyopadhyay AK. 1981. Allelopathic influences of three weeds on two crops. In: I Asian Pacific Weed Science Society Conference. APWSS: Tokyo. p.391-399.
- Duke SO, Lyndon J. 1993. Natural phytotoxins as herbicides. Available at <http://pubs.acs.org/doi/abs/10.1021/bk-1993-0524.ch009>. Accessed at Mar. 3 2011.
- Duke S, Dayan F, Rimando A. 1998. Natural Products as Tools for Weed Management. Available at http://www.snarc.ars.usda.gov/research/publications/publications.htm?SEQ_NO_115=89607. Accessed at Mar. 3 2011.
- Einhellig FA, Rasmussen JA. 1978. Synergistic inhibitory effects of vanillic and p-hydrobenzoic acids on radish and grain sorghum. *J Chem Ecol* 4:425-436.
- Erasmio EAL, Azevedo WR, Sarmiento RA, Cunha AM, Garcia SLR. 2004. Potential of species used as green manure in the integrated weed management. *Planta Daninha* 22:337-342.
- Gaffar MA, Reza MS, Rahman MM. 1998. Allelopathic effect of several plant species in controlling weeds in direct seeded Aus rice (BR-12). *Bang J Sci Indust*

- Res 33:69-73.
- Glass AD, Bohm BA. 1971. The uptake of simple phenols from barley roots. *Planta* 100:93-105.
- Glosh PK, Mandal KG, Hati KM. 2000. Allelopathic effects of weeds on groundnut (*Arachis hypogaea* L.) in India-A review. *Agric Rev* 21:66-69.
- Inderjit, Callaway RM, Vivanco JM. 2006. Can plant biochemistry contribute to understanding of invasion ecology? *Trends Plant Sci* 11:574-580.
- Ishaaya I. 2001. Biochemical processes related to insecticide action: an overview. Springer: New York. p.1-16.
- Ivashchenko AA. 1993. Characteristics of the effect of weeds. *Sakh-Sv* 2:32-33.
- Karban R. 2007. Experimental clipping of sagebrush inhibits seed germination of neighbours. *Ecol Lett* 10:791-797.
- Kendig JA. 2009. Palmer amaranth (*Amaranthus palmeri*) management. Available at <http://ncc.confex.com/ncc/2006/techprogram/P4499.HTM>. Accessed at Mar, 25 2009.
- Kissmann KG, Groth D. 1999. Plantas infestantes e nocivas. TOMO II. 2ed BASF: São Paulo. 978p.
- Larcher W. 2000. *Ecofisiologia Vegetal*. RIMA: São Carlos. 531p.
- Lolas PC. 1986. Weed community interference in barley and tobacco (*Nicotiana tabacum* L.). *Weed Res* 26:1-8.
- Lorenzi H. 2000. Plantas daninhas do Brasil: terrestres, aquáticas, parasitas e tóxicas. 3.ed. Instituto Plantarum: Nova Odessa. 640p.
- Lotina-Hennsen B, Mata R, Calderon J, Cespedes C, Jimenez M. 1998. Secondary metabolites isolated from Mexican plants: target and mechanism of action on photosynthesis. *Agric Food Chem* 2:731-749.
- Macias F, Molinillo J, Galindo J, Varela R, Torres A, Simonet A. 1999. Terpenoids with potential use as natural herbicide templates. In: Cutler H, Cutler S (eds). *Biologically active natural products: rochemicals*. CRC Press: London. p.15-31.
- Marques MA. 1992. Potencial alelopático de resíduos de caruru (*Amaranthus viridis* L.), incorporado em três tipos de solo, sobre a germinação e crescimento inicial do algodoeiro (*Gossypium hirsutum* L.). Thesis, Master, Federal University of Lavras, Lavras. 125p.
- Menges RM. 1987. Allelopathic effects of palmer amaranth (*Amaranthus palmeri*) and other plant residues in soil. *Weed Sci* 35:339-347.
- Menges RM. 1988. Allelopathic effects of palmer amaranth (*Amaranthus palmeri*) on seedling growth. *Weed Sci* 36:325-328.
- Mizutani J. 1999. Selected Allelochemicals. *Crit Rev Plant Sci* 18:653-671.
- Mohnot K, Soni SR. 1979. Presence of allelopathic principle in weeds of arid zone in relation to crop plants: effect of aqueous extract of air dried leaves of *Amaranthus tricolor* on seed germination and seedling growth of sorghum (*Sorghum vulgare*). In: Bir SS (ed). *Recent researches in plant sciences*. Kalyani Publishers: New Delhi. p49-454.
- Muminovic S. 1990. Allelopathic effect of weed extracts on germination of crop seeds. *Frag Herb Jugoslavica* 19:93-102.
- Narwall SS. 1994. Allelopathy in crop production. Scientific Publishers: Jodhpur. 288p.
- Ognjaconvic R, Stojanovic J, Lomovic S. 1995. Allelopathic effect of some weed seeds on wheat germination. *Selekcija I Semearstvo* 2:191-194.
- Ortiz Ribbing LM, Williams M. 2006. Potential of *Phomopsis amaranthicola* and *Microsphaeropsis amaranthi* as bioherbicides for several weedy *Amaranthus* species. *Crop Protec* 25:39-46.
- Pires NM, Prates HT, Pereira Filho IA, Oliveira Jr RS, Faria TCL. 2001. Allelopathic activity of leucaena on weed species. *Sci Agr* 58:61-65.
- Qasem JR. 1994. Allelopathic effects of pigweed (*Amaranthus* spp.) on barley (*Hordeum vulgare*). *Dirasat Ser B Pure Appl Sci* 21:101-120.
- Qasem JR. 1995a. Allelopathic effects of *Amaranthus retroflexus* and *Chenopodium murale* on vegetable crops. *Allelop J* 2:49-66.
- Qasem JR. 1995b. Allelopathic effects of three *Amaranthus* spp. (pigweed) on wheat (*Triticum durum*). *Weed Res* 35:41-49.
- Qasem JR. 2002. Allelopathic effects of selected medicinal plants on *Amaranthus retroflexus* and *Chenopodium murale*. *Allelop J* 10:105-122.
- Reigosa M, Pedro LN. 2002. Allelopathy from molecules to ecosystems. NH, USA, Science Publishers Inc. 316p.
- Santos JCF, Souza IF, Mendes ANG, Morais AR, Conceição HEO, Marinho JTS. 2001. Allelopathic influence of coffee (*Coffea arabica* L.) and rice (*Oryza sativa* L.) husks mulches on the control of slender amaranth (*Amaranthus viridis* L.) in coffee plantation. *Ci Agrotec* 25:1105-1118.
- Santos JCF, Souza IF, Mendes ANG, Morais AR, Conceição HEO, Marinho JTS. 2002. Effect of extracts of coffee and rice husks upon emergence and growth of the slender amaranth. *Pesq Agropec Bras* 37:783-790.
- Singh UO, Wadhwani AMO, Johri BM. 1983. Dictionary of economic plants of India. 2.ed. ICAR: New Delhi. 188p.
- Singhal BK, SEN DN. 1981. Allelopathic potential of pigweed (*Amaranthus viridis* Linn.) on rainfed crops of Indian desert. *Geobios* 21:213-221.
- Suma S. 1998. A brief study on the environmental physiology of *Amaranthus spinosus* L. Thesis, Doctorate, Bangalore University, Bangalore. 112p.
- Suma S, Ambica SR, Kazinczi G, Narwal SS. 2002. Allelopathic plants. 6. *Amaranthus* spp. *Allelop J* 10:1-12.
- Trebs A, Draber W. 1986. Inhibitors of photosystem II and the topology of the herbicide and Q_B binding polypeptide in the thylakoid membrane. *Photosynth Res* 10:381-392.
- Tucker JM, Sauer JD. 1958. Aberrant *Amaranthus* populations of Sacramento San Joaquin delta California. *Madrono* 14:252-261.
- Uphof JC. 1968. Dictionary of economic plants. Cramer: New York. 545p.
- Velu G, Ali AM. 1995. Allelopathic effect of pigweed and horse purslane on *Boerhaavia diffusa*. *Crop Res* 10:103-106.

- Velu G, Kempuchetty N, Palaniappan SP. 1990. Crop response to allelopathic effect of *Amaranthus*. Res Develop Rep 7:193-196.
- Wiersema JH, Leon B. 1999. World economic plants. CRC Press: Boca Raton. p.32-34.
- Willis JC. 1973. A dictionary of the flowering plants and ferns. Cambridge University Press: Cambridge. 1236p.
- Wright K, Pillmor J, Briggs G. 1991. Rationality in herbicide design. In: Baker NR, Percival MP (eds). Herbicides. Elsevier: Amsterdam. p.337-364.

Received on July 16, 2011.

Accepted on September 20, 2011.

Online published on September 29, 2011.