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Review

Biological, ecological and agronomic significance of plant phenolic compounds in rhizosphere of the symbiotic legumes

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Phenolics are low molecular compounds ubiquitous in all tissues of higher plants with great significance in plant development. Our understanding of some phenolic compounds in the last few decades has greatly improved. However, their biological, ecological and agronomical significance in the rhizosphere of most symbiotic legumes is much less clear. Further understanding of these biomolecules will increase our knowledge of their contribution in soil and water conservation, weed management, mineral element nutrition, their impact as signal molecule in certain symbiotic relationships, and their role as defence molecules against soil pests and pathogens. This article reviews the bio-ecological and agronomical significance of phenolic compounds in the rhizosphere of a few studied symbiotic legumes and other plants.

Key words: Allelopathy, defence, flavonoids, growth inhibitors, soil structure, nutrients availability, pesticide, signal molecules, soil borne diseases, soil insects.

INTRODUCTION

Phenolic compounds are some of the most widespread molecules among plant secondary metabolites, and are of great significance in plant development. They are involved in diverse processes including rhizogenesis (Curir et al., 1990), vitrification (Kevers et al., 1984), resistance to biotic and abiotic stress (Delalonde et al., 1996), and redox reactions in soils (Takalama and Oniki, 1992). Additionally, they serve as flower pigments, act as constitutive protection agents against invading organisms, function as signal molecules, act as allelopathic compounds, and affect cell and plant growth (Dakora, 1995; Dakora and Phillips, 1996; Ndakidemi and Dakora, 2003), are important natural animal toxicants (Adams, 1989) and some may function as pesticides (Vidhyasekaran, 1988; Waterman and Mole, 1989; Beier, 1990). They are also functional components of the rhizosphere and its soil organic matter (Haider et al., 1975; Martin and Focht, 1977). They have long been recognised as allelochemicals for weed control (Rice, 1984; Putnam and Tang, 1986) phytoestrogens in animals (Adams, 1989) and plant defence molecules (Vidhyasekaran, 1988). In the rhizosphere, they act as important precursors for the synthesis of soil humic substances (Haider et al., 1975).

The synthesis and release of phenolics are induced by various biotic and abiotic factors. Boron deficiency can, for example, induce the accumulation of phenolics in plants. Tissue injury, pathogen attack, herbivory, and infection by microsymbionts such as rhizobium can also cause synthesis and release of phenolics (Recourt et al., 1991; Dakora et al., 1993a, b; Lawson et al., 1996). Inside and outside plant tissues, these metabolites are known to function as phytoalexins, phytoanticipins and node gene inducers (Dakora and Phillips, 1996, 2002). Although several authoritative reviews have examined phenolic molecules in plant development (Long, 1989; Bekkara et al., 1998; Dakora and Phillips, 1996), few have assessed

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their role in the quality and function of rhizosphere soil. This paper discusses phenolics as major players in soil function and plant growth.

PHENOLICS AS MODIFIERS OF RHIZOSPHERE SOIL STRUCTURE

In the rhizosphere, soil particles are bound together by phenolics and other exudate compounds from roots, microbes and decomposing organic matter to form aggregates, thus providing support for plant roots. As a living biological system, the soil consists of plant roots, micro flora and micro fauna whose chemical products bind with soil particles to enhance aggregation.

Phenolics and other organic molecules from root and seed exudates, leaf leachetes, and decaying plant residues, play a major role in soil formation and pedogenesis. Because some phenolic metabolites are phytotoxic, their presence in higher concentrations can affect soil function (Patrick, 1971; Lodhi, 1975; Chou and Lin, 1976; Rice, 1984; Putnam and Tang, 1986; Elliott and Cheng, 1987; Waller, 1987). The quantity and quality of phenolics released by plants can differ from species to species. For example, ryegrass roots have a much higher tissue concentration of phenolics than red clover (Whitehead et al., 1979). The concentration of phenolic acids in soil can range from 2.1% to 4.4% for roots of monocots and 0.1% to 0.6% for dicots (Hartley and Harris, 1981; Smith and Hartley, 1983; Hartley and Whitehead, 1985).

The release of phenolic compounds by plants can vary with time, space, and location. In *Cistus albidus* green leaves, phenolic concentration ranged from 66.5 to 95.9 mg garlic acid g^{-1} DM depending on the time of the year and the soil type, with maximum phenolic accumulation in winter and when growing on granitic and schistic soils (Eva and Josep, 2003). In valley bottom ecosystems, the concentration of individual phenolic acids (*p*-coumaric acid) was as high as 6.7% in January, but dropped to 2.0% in September (Lodhi, 1975), a decrease attributed to leaching, plant uptake, and microbial transformation (Martin et al., 1972; Turner and Rice, 1975; Martin and Haider, 1976). These situations suggest that phenolics in soil-plant continuum undergo a continuous cycle of deposition, decomposition, plant uptake, leaching and chemical immobilisation. In short, as phenolics moves through the rhizosphere, they may be transformed, metabolised by microbes, or bound by soil organic matter. In doing so, the soil structure is shaped, thus improving both soil porosity and plant growth.

Soil structure, soil macro and micro porosity in the rhizosphere may be improved by phenolic compounds in favour of air and water movement for both abiotic and biotic life in the soil ecosystem. Therefore, understanding their functional groups will be of vital importance for the overall improvement of agricultural production systems. Additionally, understanding which plant releases what type and amount of phenolic compound(s) will be of utmost importance for better soil and water conservation.

ROLE OF PHENOLIC COMPOUNDS ON NUTRIENT AVAILABILITY IN THE RHIZOSPHERE

Phenolics are known to play a dominant role in rhizosphere mineral elements and organic matter dynamics by affecting organic matter degradation, humus formation, alteration of microbial activities, mineralization of N and its availability (Schimel et al., 1996; Northup et al., 1998; Hattenschwiler and Vitousek, 2000; Kraus et al., 2003). Although the uptake, metabolism and toxic effects of most phenolics in the rhizosphere of many plants are well documented (Curir et al., 1990; Klein and Blum, 1990), their biochemical mechanisms, biosynthesis, release and functioning as affected by the host plants such as legumes are to a large extent unknown.

Phenolics can have both negative and positive influence on plant mineral elements availability in the rhizosphere. There is evidence that green leaves and decomposing litter from plants can influence rhizosphere N dynamics through rainfall leachate of phenolics as chlorogenic acid (Eva and Josep, 2003), or through different mechanisms which alter phenolic synthesis. These mechanisms include formation of protein complexes, which in turn delays organic matter decomposition and mineralization (Horner et al., 1988; Nicolai, 1988; Oades, 1988; Palm and Sanchez, 1990; Bending and Read, 1995; Northup et al., 1995, 1998; Hoenschwiler and Vitousek, 2000); increase of microbial activity when used as carbon source (Sparling et al., 1981; Schimel et al., 1996; Schmidt et al., 1997; Blum, 1998; Fierer et al., 2001); N immobilization (Shafer and Blum, 1991; Sugai and Schimel, 1993; Schimel et al., 1996; Blum, 1998) and direct inhibition of nitrification (Rice, 1984; Boufalis and Pellissier, 1994). From these mechanisms, plants growing on infertile soils could benefit from the sequestered N into a large unavailable pool of recalcitrant organic matter.

Phosphate supply is one of the major constraints to plant growth due to its insolubility and high sorption capacity in soil (Marschner, 1995). However, there is now overwhelming evidence suggesting that some plants may directly modify their rhizosphere in order to gain access to unavailable soil P reserves (Morel and Hinsinger, 1999). These rhizosphere modifications include the release of phenolics, such as syringic, caffeic, and protocatechuic acids which then can solubilize and accumulate inorganic P. It has now been demonstrated that some plants such as *Lupinus albus* and *Brassica napus* are capable of releasing large amounts of phenolics into the rhizosphere in response to P deficiency (Laheurte and Berthelin, 1988; Hoffland et al., 1992; Gerke, 1994; Johnson et al., 1996; Imas et al., 1997). These phenolics may, in turn, improve plant P availability by interacting with metal oxides which could otherwise fix P, or desorb phosphate from sesquioxide surfaces by anion (ligand) exchange (Parfitt, 1979; Gerke, 1992). Detailed physiolological and biochemical studies to identify other specific role(s) phenolics can play in supplying P to plants are recommended.

Phenolics may also increase the availability of macro and micro elements (e.g. K, Ca, Mg, Cu, Zn, Mn, Mo, B) through formation of organic metal complexes and by providing sorption sites (Marschner, 1988; Hoffland, 1992; Slabbert, 1992; Marschner, 1995; Micales, 1997).

Phenolic acids are strong metal complexing agents representing a major group of organic acids that can affect solution concentration of cations, mobility, bioavailability and facilitation of nutrient uptake especially Fe (Tiarks et al., 1989; Slabbert, 1992; Scalbert et al., 1999; Seneviratne and Jayasinghearachchi, 2003). Under acid condition some plants such as legumes have been reported to release reductant compounds that enhance uptake of Fe (Osen et al., 1979). For example, the growth of excised pea roots (DeKock and Vaughan, 1975) and Fe-deficient tomato plants were promoted by enhancing Fe uptake when phenolics were added in the medium (Osen et al., 1981). The mechanism involved is that *p*-coumaric acid released by roots or decaying residue is hydroxylated into caffeic acid that can reduce Fe^{3+} and increase its mobilisation as shown in the following equation:

$$\text{Caffeic acid} + Fe^{3+} \rightarrow \text{caffeoyl-}o\text{-quinone} + 2Fe^{2+} + 2H^{+}$$

Copper (Cu) plays an important role in plant growth including nodulation and N_2-fixation in legumes (Cartwright and Hallsworth, 1970). Marked differences have been observed in Cu^{2+} nutrition between plants growing in Cu^{2+} enriched and non-contaminated soils (Ernst et al., 1992). The mechanism enabling plants to tolerate high concentrations of Cu^{2+} in their rhizosphere are still poorly understood. However, *in vitro* adsorption studies by Jung et al. (2003) showed that phenolics such as flavonoids and polyphenols mediated Cu^{2+} toxicity in the rhizosphere and roots apoplasm through complexations of Cu^{2+} ions, thus alleviating the Cu^{2+} toxicity. Further studies on the mechanisms involving Cu^{2+} nutrition and phenolic compounds should be undertaken in the rhizosphere of symbiotic legumes.

Aluminium (Al) rhizotoxicity is one of the biggest limitations to crop production in the world and is characterized by the inhibition of root cell elongation and to a lesser extent cell division (Kochian, 1995; Kochian and Jones, 1997). However, through phenolic compounds, some plants appear to be able to resist toxic concentrations of Al (>5 µM) in plants (Powel and Rate, 1987; Kochian, 1995; Ma et al., 1997). For instance, Kidd et al. (2001) showed that exposing maize roots to higher Al concentration resulted in higher exudation of penta-hydroxy-flavone and morin phenolic compounds.

These molecules are known to have metal binding activity in plants (Kochian, 1995; Ma et al., 1997). More research efforts should explore other phenolic compounds and the mechanism(s) involved in defending plants against this toxic element.

On the contrary, phenolic toxicity has also been reported to cause severe mineral elements deficiency in rhizosphere. For instance, maize plant growing in agricultural soil infested with *Agropyron repens*, a strong allelopathic weed rich in phenolics, suffered from severe deficiency of N, P and K (Buchholtz, 1971; Rice, 1984). The inhibition of these phenolics to K and P uptake was correlated with octanol-water partition coefficients and lipid solubility of the phenolics respectively. Thus, further studies on inhibition of other mineral elements by phenolic compounds are a subject that warrants further investtigation. Understanding of these compounds and application may lead to greater revolution in soil fertility.

PHENOLICS AS PLANT GROWTH INHIBITORS IN THE RHIZOSPHERE

Growth-inhibiting compounds of agricultural importance have recently received considerable research attention (Siqueira et al., 1991; Inderjit, 1996). These compounds include phenolic compounds with allelopathic characteristics (Schenk et al., 1999; Callaway and Aschhoug, 2000). Allelopathy is an adverse influence of one plant or micro-organism on another (Rice, 1984) or production of active chemicals by living or decaying plant tissues which interfere with the growth of neighbouring plants (Muller, 1969; Rice, 1984; Putnam and Tang, 1986; Waller, 1987; Weidenhamer et al., 1989; Schenk et al., 1999; Callaway and Aschhoug, 2000). Studies have shown that these chemicals include simple phenols, phenolic acids derived from benzoic and cinnamic acids, coumarins, flavonoids, isoflavonoids, tannins and a variety of phenolic conjugates (Figures 1, 2 and 3). Their presence and accumulation in the soil may reach the threshold concentrations for inhibition of pre-emergence seed germination or post-germination, growth and other plant functions (Whitehead, 1964; Baskin et al., 1967; Einhellig, 1986; Leather and Einhellig, 1986, Fisher, 1987; Patterson, 1987). Different phenolics concentrations have been reported to inhibit seed germination and seedling growth in legumes (Beier et al., 1983; Zaynoun et al., 1984). For instance, 50% inhibition of germination and seedling growth required concentration of phenolic acids ranging from 150 – 1000μg mL^{-1} for rye grass and Lucerne (Guenzi and McCalla, 1966).

Other phenolics such as myrcetin, quercetin, and myrcitrin have been identified as seed coat rhizobium toxins (Fottrell et al., 1964) and prodelphindin, quercetin, rutin, cathecol, *p*-coumaric, gentistic, salicyclic and vanillic acids as rhizobia cell, bacteria and fungi inhibitors (Table 1; Debman and Smith, 1976; Skipp and Bailey, 1977; Kandasamy and Prasad, 1979; Pankhurst and Biggs, 1980; Adesanya et al., 1986; Thompson, 1988). It is, therefore, important to identify more phenolic compounds inhibiting plant growth and micro-organisms in the rhizo-

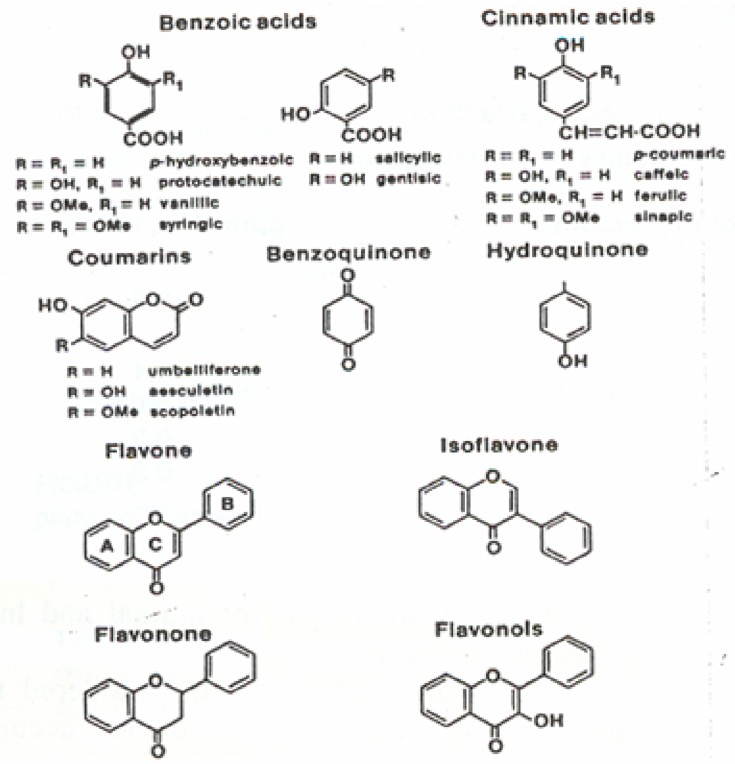

Figure 1. Chemical structures of selected phenolic compounds from legumes.

sphere, and have a better understanding of their roles and mechanisms involved in such interactions for better management of ecosystems.

Despite the fact that we have a considerable understanding of phenolics as allelochemicals and their allelopathic effects, there are still some noxious weeds such as *Striga* which retard plant growth and cause severe yield losses in cereals and legumes worldwide. Understanding of different phenolic compounds from various plant species including legumes and their allelopathic effects, and how best they can be used for weed management such as *Striga* and other parasitic weeds is vital.

PHENOLICS AS SIGNALS TO SYMBIOTIC RHIZOBIA AND VESICULAR-ARBUSCULAR MYCORRHIZAL

The exudation of low molecular weight compounds by seeds in the soil or in plant root is known to activate the expression of *nod* genes (Innes et al., 1985; Mulligan and Long, 1985; Rossen et al., 1985; Firmin et al., 1986; Peters et al., 1986; Redmond et al., 1986; Horvath et al., 1987; Spaink et al., 1987; Dakora et al., 1993; Leon-Barrios et al., 1993; Dakora, 1994; Phillips et al., 1994). These organic molecules include, amongst others, the phenolic compounds (Table 2). Many varieties of phenollic identified as *nod* gene inducers have been well described in Dakora et al. (1993); Leon-Barrios et al. (1993); Dakora, (1994)**;** Phillips et al. (1994); Ndakidemi and Dakora (2003). For instance, broad bean (*Vicia faba*) releases flavones and flavonols (Bekkara et al., 1998), soybean releases isoflavonoids (D'Arcy-Lameta and Jay, 1987) and peanut releases vanillin (Zawoznik et al., 2000). Such phenolics can accumulate in legume rhizosphere and facilitate *nod* gene induction and control the nodule formation (Dakora et al., 1993; Leon-Barrios et al., 1993; Dakora, 1994**;** Phillips et al., 1994; Dakora and Phillips, 1996).

The contribution of vesicular-arbuscular mycorrhizal to increased P acquisition and improvement of water relations of crop plants in our agricultural systems has been extensively reviewed (Smith and Read, 1997) and the role of phenolics in mycorrhizal establishment has also been reported (Anderson, 1988; Paula and Siqueira, 1990). For example, phenolic compound isoflavonoid from roots of soybean promoted the colonization of vesicular-arbuscular mycorrhizal fungi in soybean (Morandi and Bailey, 1984; Morandi, 1989; Wyss et al., 1989). Seed exudates from white clover identified as biochanin A, chrysin and formononetin also promoted the colonisation of AM fungi (Siqueira et al., 1991). Summing up these findings, the colonization of vesicular-arbuscular mycorrhizal at low soil P availability has been related to the accumulation of specific phenolic compounds capable of stimulating hyphal growth, appressorial formation and penetration of vesicular-arbuscular mycorrhizal fungi. Further understanding of the relationship between phenolic accumulation and vesicular-arbuscular mycorrhizal

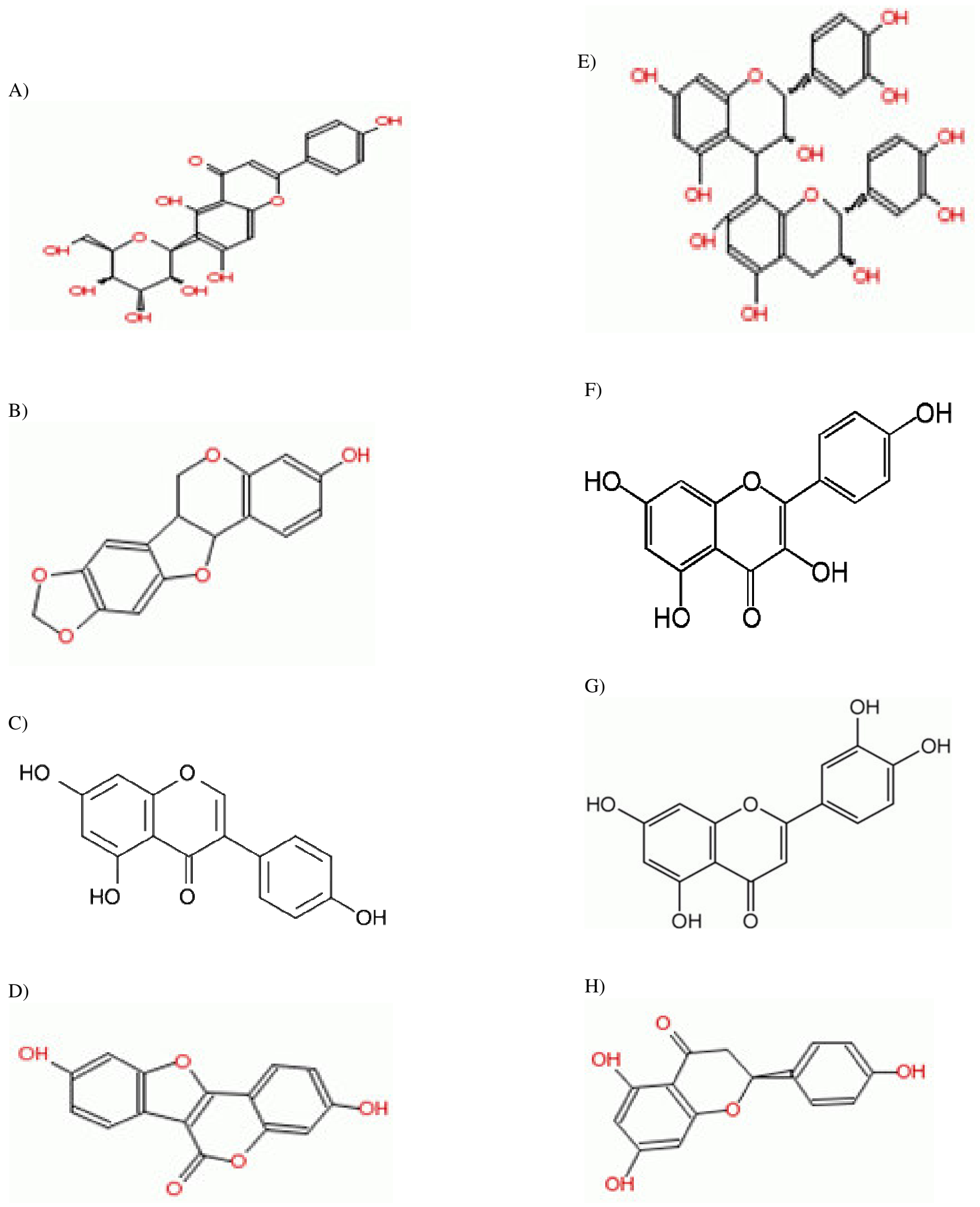

Figure 2. Chemical structures of selected biologically active flavonoid-derived compounds: A) Isovitexin B) Maackiain C) Genistein D) Coumestrol E) Procyanidin F) Kaempiferol G) Luteolin H) Naringenin.

formation is therefore, of utmost importance. This is because manipulation of phenolic compounds may lead to higher vesicular-arbuscular mycorrhizal infections, leading to greater P acquisition for plant nutrition, improved water relations and consequently resulting in better plant growth.

Although several studies have shown that a wide range of phenolic compounds such as flavonoids, alkaloids, isoflavonoids, flavonols, luteolin, quercetin, trigonelline, stachydrine and kaempferol are signal molecules in the rhizosphere (Peters et al., 1986; Hartwig et al., 1990; Hungria et al., 1991; Dakora, 1994**;** Phillips et al., 1995), it will not be surprising to uncover a large number of other unknown phenolic compounds being involved in *nod* gene induction processes and mycorrhizal infections. Based on these facts, more research and understanding of the production and release of signal molecules from different legume species is needed.

PHENOLICS IN THE RHIZOSPHERE AS DEFENCE MOLECULES AGAINST SOIL-BORNE PATHOGENS

The consequences imposed by soilborne pathogens in our agricultural systems may favour different defence strategies by plants in their rhizosphere. There is a trem-

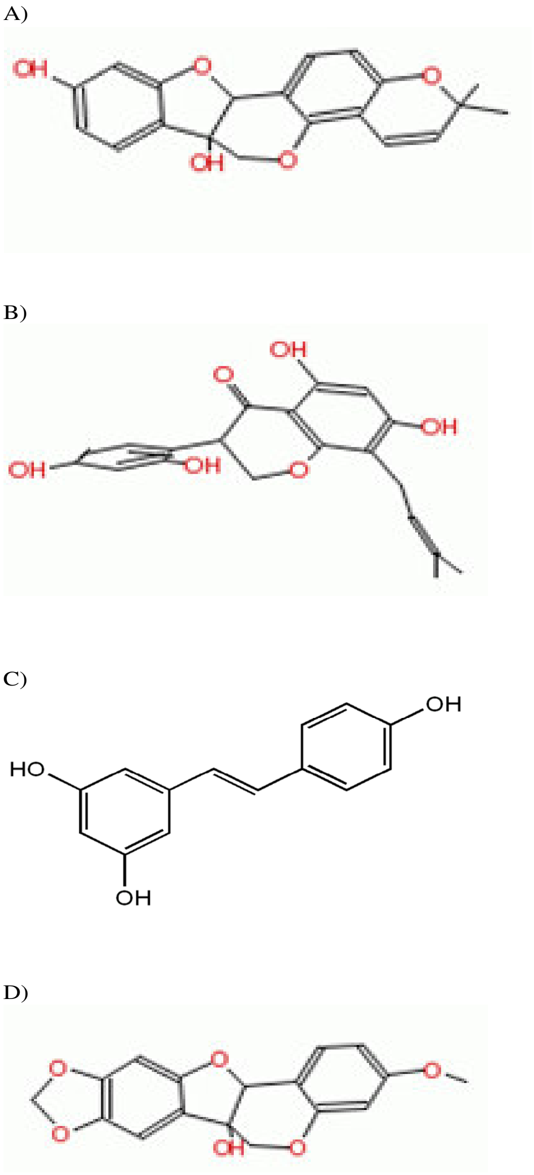

Figure 3. Chemical structures of selected phenolic compounds against plant pathogens: A) Glyceolin B) Kievitone C) Resverastrol D) Pisatin.

endous pressure on farmers to use safe control methods for soilborne diseases which do not pollute or degrade the environment (Dunkan, 1991; Akhtar, 1995). Fortunately, phenolic compounds can offer an alternative to the chemical control of pathogens on agricultural crops (Tables 1 and 3). Studies have shown that plant defence against pathogens, nematodes, phytophagous insects is based on the synthesis, release and accumulation of various phenolic compounds (Rich et al., 1977; Russel et al., 1978; Dakora, 1995; Dakora and Phillips, 1996). For example, simple and complex phenolic compounds such as cajanin, medicarpin, glyceolin, rotenone, coumestrol, phaseolin, phaseolinin are known to accumulate in tissue of tropical legumes and act as phytoalexins, phytoanticipins and nematicides against soilborne pathogens and phytophagous insects (Dakora and Phillips, 1996; Ndakidemi and Dakora, 2003; Tables 1 and 3). Alfalfa roots release isoflavonoid 2-(3′5′-dihydroxyphenyl)-5, 6-dihydroxybenzofuran which saves as phytoallexin against root pathogens such as *Fusarium oxysporum* f. sp. *Phaseoli* (Massaoka et al., 1993). Generally, when released into the soil from seeds, roots or residue decomposition, these molecules can act against soilborne pathogens and root-feeding insects (Ndakidemi and Dakora, 2003). Such natural defence provided by these biomolecules from symbiotic legumes in the rhizosphere deserves more scientific attention because of its ecological potential as a sustainable means of reducing soil borne infections in the ecosystems. To date, few studies have validated the role of phenolics against the soil borne pathogens. Therefore, establishing the biological significance of these molecules from unexplored legumes and other plant species could help in the integrated soilborne pathogen control programmes.

PHENOLICS AS PESTICIDAL MOLECULES AGAINST SOIL INSECTS

It is widely documented that plants produce a wide variety of secondary metabolites as defensive weapons against insect pests during attack (Dakora, 1995; Dakora and Phillips, 1996; Ndakidemi and Dakora 2003; Table 3). These include alkaloids, terpenoids, phenolic compounds, and many others (Ndakidemi and Dakora 2003). During the past few decades researchers have identified plant extracts highly effective against a good number of plant pests (Dakora, 1995; Dakora and Phillips, 1996; Ndakidemi and Dakora 2003). The most active documented compounds have been isolated from the Neem tree (Egunjobi and Afolami, 1976; Badra and Eligindi, 1979; Thakur et al., 1981, Muller and Gooch, 1982; Akhtar and Alam, 1993; Akhtar and Mahmood, 1996; Akhtar, 1998; Akhtar and Malik, 2000). Phenolic compounds ext-racted from different parts of Neem tree include: limo-noids, phenols, tannins, nimbin, salanin, thionemone, azadirachtin and various flavonoids. These compounds have been found to possess nematicidal properties and are also reported to be highly effective against nematodes and insects (Badra and Eligindi, 1979; Thakur et al., 1981, Akhtar and Malik, 2000; Table 3). Scientists working with symbiotic plants should find out if similar or other active compounds exist in their tissues.

Studies with a few symbiotic plants have also shown that the presence of the isoflavonoid vesitol in roots of legume *Lotus pedunculatus* made it resistant to the larvae of black beetle (*Heteronychus aratoo*) attack (Russel et al., 1978). Plants were susceptible to the same pest in a similar genus of different specie (*Lotus corniculatus*) that was lacking the compound vesitol in their roots (Russel et al., 1978).

Table 1. Phenolics compound inhibitors of micro-organisms.

Micro-organism	Phenolic compound	Reference
Fungi	Catechol, sinarpic, phaseolin, phaseolidin, phaseolin isoflavan, kievitone, medicarpin, *p*-coumaric, ferulic, gentisic, benzoic, caffeic, *p*-coumaric, salicyclic acid, benzoquinones, engenol, vanillin, gallic acid, pisatin, genistein, maackianin daidzein, isoprunetin, phaseoluteone, isoferrinin, isomeclycarpin, glyceollin, glyceollin 1 coumestran, biochanin A, echinacin	Lingappa and Lockwood, 1962; Christie, 1965; Li et al., 1969; Choudhury et al., 1974; Keen, 1975; VanEtten, 1976; Debman and Smith, 1976; Skipp and Bailey, 1977; Wymann and VanEtten, 1978; Alfenas et al., 1982; Kramer et al, 1984; Stossel, 1985; Adesanya et al., 1986; Kasenberg and Traquar, 1988; Achenbach et al., 1988; Singh et al., 1988; Ravin et al., 1989; Weidenborner et al., 1989 & 1990.
Bacteria	Phaseolin, phaseolin isoflavan, kientone, quercetin-glucoside, myraccetin quercetin, tanins, syringic, *p*-hydrobenzoic, ferulic, caffeic, chlorogenic, pisatin,	

Table 2. Phenolic compounds as *nod* gene inducers found in germinating seeds and root exudates of selected legume plants.

Legume	Phenolic compound	Functional role	Reference
Alfalfa (*Medicago sativa* L.)	3′,4′, 5, 7 tetrahydroxyflavone; 3 methoxyluteolin; luteolin; luteolin-7-*O*-glucoside; 5-methoxyluteolin; 5-methoxycrisoeriol; 3-*O*-quercetin galactoside; trigonelline; stachydrine 7,4′-dihydroxyflavone, 7-hydroxyflavone, 4,4′-dihydroxy-2-methoxychalcone, chrysoeriol, 2′-methoxychalcone	*nod* gene inducers	Peters et al., 1986; Kapulnik et al., 1987; Maxwell et al., 1989; Hartwig et al., 1990; Phillips et al., 1995;
	quercetin, 4,7′-dihydroxyflavonone,	AM hyphal growth inducer	Tsai and Phillips, 1991
Cowpea (*Vigna unguiculata* L.)	Daidzein, genistein, coumestrol	*nod* gene inducers	Dakora et al., 2000
Bean (*Phaseolus vulgaris* L.)	Genistein, genistein-3-*O*-glucoside, pentunidin, malvin, myricetin, quercetin, daidzein, coumestrol, kaempferol, naringenin, eriodictyol	*nod* gene inducers	Hungria et al., 1991, Dakora et al., 1993
Clover (*T.repens L. and T.incarnatum* L.)	7, 4′-dihydroxyflavone, geraldone, formononetin, umbelliferone.	*nod* gene inducers	Peters et al., 1986; Djoedjevic et al., 1987; Hartwig et al., 1990
Pea (*Pisium sativum* L.)	Eriodictyol, aspigenin-7-O-gluciside, apigenin	*nod* gene inducers	Firmin et al., 1986
Faba bean *(Vicia faba* L.)	Naringenin, eriodictyol, apigenin, luteolin hesperetin	*nod* gene inducers	Zaat et al., 1987; Zaat et al., 1989
Soybean (*Glycine max*)	Genistein, genistein-7-O-glucoside, genistein-7-O-(6”-O-malonylglucoside), isoliquiritigenin, narigenin daidzein, daidzein-7-O-(6”-O-malonylglucoside), coumestrol, 7,4′-dihydroxyflavone	*nod* gene inducers	Van Brussell et al., 1986; Kosslak et al., 1987; Bassan et al., 1988; Sadowsky et al., 1988

Although there is a high potential for finding phenolic compounds with insecticidal properties in symbiotic legumes and other plant species, to date, only a few molecules controlling soil insects have been identified. The available literature does not seem to offer enough information on the mechanisms and the effect of molecules extracted from different symbiotic plants on harmful soil pests. The possibility to uncover more and use them in soil pest control seems to be considerable. For this to become true, extensive research programmes must be initiated to identify more phenolic plant products with insecticidal activity towards harmful soil insects.

CONCLUSION

Understanding new roles of phenolics and their functional groups is vital for better rhizosphere fertility, soil pest control and the overall production ecosystems. Better understanding of which plants give what type and amount of which phenolics to be incorporated in our cultural practices will eventually solve problems such as soil and water conservation, soil fertility, nutrients conser- vation, and soil pests management. However, in order to exploit the rich knowledge achieved and to merit the efforts used so far, collective action among researchers is required to

Table 3. Phenolics compounds from common legume roots potential in defence against soil borne pests in cropping systems.

Legume	Phenolic compound	Functional role	Reference
Lotus pendunclatus	Vestitol	Insect deterrent	Russel et al., 1978
Soybean (*Glycine max* L.)	Glyceollin	Insect deterrent, phytoalexin	Dakora and Phillips, 1996
Cowpea (*Vigna unguiculata* L.)	Medicarpin	Insect deterrent, phytoalexin	Dakora and Phillips, 1996
	Kievitone	Antifungal	Keen, 1975
Bean (*Phaseolus vulgaris* L.)	Phaseolin	Insect deterrent, phytoalexin	Dakora and Phillips, 1996
Lima bean (*Phaseolus lunatus* L.)	Coumestrol	Nematicide	Rich et al., 1977
Pigeon pea *(Cajanus cajan)*	Cajanin	Insect deterrent, phytoalexin	Dakora and Phillips, 1996

develop detailed genetic, biochemical and physiological programmes involving phenolic compounds. Furthermore, our research should aim at the most appropriate combination of factors for the best use of the phenolics to improve plant and beneficial microbial growth as well as better the biological environments sustaining other life types.

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