Biological Sciences in Space, Vol.17 No.1 (2003): 4-5

Application of Allelochemicals to Agriculture

Nobuhiro Hirai

International Innovation Center, Kyoto University, Kyoto 606-8501, Japan

Abstract The study of allelopathy has a long history, and its application to agricultural production has long been anticipated. Recently, researchers have found allelopathic plants that are now used as cover crops, and allelochemicals which may lead to new herbicides. This paper reviews three studies introduced in this symposium, and discusses the possible application of allelopathy to agriculture.

Key words: abscisic acid, allelopathy, cyanamide, flavonoid, momilactone.

The study of allelopathy has numerous aspects, such as ecology, plant physiology, molecular biology, natural product chemistry, and agriculture. Researchers in various areas attended to the symposium, and actively discussed allelopathy. The symposium had several speakers. I review here the topics of the first session I chaired. The session had three speakers, Dr. Y. Fujii, Profs. F. A. Macias, and T. Iwashina.

Many allelopathic plants have been reported so far, but it is not easy to find a new plant with such ability. Dr. Y. Fujii is a specialist in allelopathy, and has been working in allelopathy for more than 20 years. He has not only developed bioassay methods using agar media to find allelopathic activity in plants in the laboratory, but also has tested for allelopathy in the field. A lot of plants have been screened for allelopathy by his methods, and many allelopathic plants and allelochemicals have been found by him. The latest achievement of his research group was the identification of the allelochemical of hairy vetch. Hairy vetch (*Vicia villosa* Roth), a leguminous plant, is utilized as a cover crop to provide nitrogen to soil, and to prevent soil erosion. The advantage of this plant as a cover crop is suppression of weed growth after the plant wilts. Dr. T. Kamo (2003) of his group identified cyanamide as its active substance, the first report of the natural occurrence of cyanamide, which has been identified as an artificial fertilizer. Cyanamide may be an endogenous fertilizer to supply nitrogen, although its function is unclear. Allelopathy and allelochemicals of another cover crop (*Mucuna pruriens*), an ornamental plant (*Duranta repens*), a tropical weed (*Sphenoclea zeylanica*) and others have also been reported by his group.

In the application of allelopathy to agriculture, using allelopathic plants as cover crops seems to be the most promising use, however, the final goal may become development of major crops with allelopathy. Such crops could decrease the amount of both herbicides and labor time, although we should avoid the invasion of allelopathic crop species into the natural ecosystem. The rice plant is a good target, as well as wheat and maize plants. Momilactone B was identified as a plant growth inhibitor in water culture of rice plants, suggesting that the compound is an allelochemical of rice plant (cv. Koshihikari) (Ino & Kato, 2003). Recently, a cultivar PI 312777 of rice has been reported to suppress growth of a weed, barnyard grass (Geary, 2002), but it has not been examined whether momilactone B is involved in allelopathic activity of the cultivar. Several groups including Dr. Fujii's are continuing screening of many cultivars for allelopathic rice, and trying to identify genes responsible for allelopathy. If biosynthetic enzyme genes of allelochemicals are found, the gene could be introduced into commercial cultivars. Their challenging research is expected to be fruitful in the near future.

Natural inhibitors of plant growth are a good source to develop herbicides by chemical modification to increase activity and selectivity (Duke *et al*., 2002). Cinmethylin, an herbicide, is a good example of this approach. This compound is a derivative of 1,4-cineole, an allelochemical of eucalyptus. There are still many allelochemicals that may lead to herbicides, but they have not been utilized. Professor F. A. Macias, an organic chemist for natural products, is famous for his achievements in isolation and identification of heliannuol A and B as allelochemicals of the sunflower plant. He introduced chemical research on sesquiterpene lactone to develop derivatives with higher activity by modification of two functional groups. Lipohylicity of compounds is an important factor since compounds permeate into plant cells through a plasma membrane consisting of lipid bilayer. The lipophylicity of isozaluzanin C was increased by introduction of acyl groups at the 3-hydroxyl group. Some derivatives with branched acyl groups showed higher inhibitory activity than that of isozaluzanin C. Another target for modification is the enone group. Since an enone group can act as a Michael addition acceptor, which forms conjugates with nucleophiles including glutathione and other biologically important substances, modification of an enone group could change phytotoxicity. The double bond of an enone group in sesquiterpene lactones, dehydrocostuslactone and cynaropicrin, was substituted with oxetane-related groups, to mask the Michael addition acceptor. The groups could

Received: May 6, 2003

Address for correspondence: Nobuhiro Hirai
International Innovation Center, Kyoto University, Kyoto 606-8501, Japan
E-mail: hirai@kais.kyoto-u.ac.jp

be converted to an enone group under a basic condition or metabolism in plants. The phytotoxic activity of the derivatives changed, suggesting that phytotoxicity can be decreased by masking an enone group.

These derivatives could be herbicides, if large amounts of the compounds are available to verify their activity in the field.

Flavonoid is widely seen in plant kingdom, ranging from liverwort to higher plants. Some flavonoids occurring in flowers as pigments attract birds and insects for transportation of pollen. On the other hand, the physiological functions of flavonoids in leaves is unclear. Professor T. Iwashina suggested that the most important function of flavonoids is to protect biomolecules in plant cells from UV light. Flavonoid, as well as carotenoid, may be essential for such protection, so that plants can survive under the sunlight. Furthermore, he suggested that flavonoids have various functions that relate to ecological systems including insects and microorganisms. Flavonoids in Aristolochiaceae and Rutaceae stimulate oviposition of butterflies, and flavonoids in Morus are feeding stimulants for insects. In roots of leguminous plants, flavonoids trigger infection of rhizobium, root nodule bacteria. These allelochemical functions of flavonoids have not fully been utilized to control damage made by insects or promotion of rhizobium infection. Allelopahtic effects should be considered not only with regard to plant growth but also concerning insects and microorganisms. Such a view could also contribute to realizing sustainable agriculture.

To conclude this review, I would like to propose a problem of abscisic acid that was not discussed in the symposium. Abscisic acid is an important plant hormone that regulates physiological adaptation to environmental stresses such as water deficiency, osmotic stress and low temperature, during embryonic development, and other functions (Leung and Giraudat, 1998). The hormone may function as an allelochemical in some cases. Citrus peels shows suppression of weed growth when the peels are applied on soil surface. Kato *et al*. (2002) found that the active substance was glucosyl ester of abscisic acid, and that the ester was contained in the peel at a high level. The active mechanism of the suppression is associated with abscisic acid produced by hydrolysis of the ester. In this case, abscisic acid seems to be leaked from the peel by degradation of cells. Other researchers have suggested that abscisic acid is released from intact plants. Toyomasu *et al*. (1994) reported that abscisic acid was detected in culture media where lettuce seeds were germinated. The authors have not discussed the physiological role of abscisic acid in the media, but it is an interesting finding since it means that a hormone important for plants is secreted or released to the environment. Hartung *et al*. (1996) detected abscisic acid in aqueous extracts from soils at concentrations of 0.6-2.8 nM, and the concentration was highest in acidic soils with reduced moisture. They also found that abscisic acid in soil was quickly degraded, probably by microorganisms. Abscisic acid in the soil of maize fields increased during the vegetative period. This finding suggests that abscisic acid in soils was released from intact roots in addition to debris of roots and leaves. A typical effect of abscisic acid on plants is inhibition of growth and germination, so that abscisic acid released from intact plants may suppress growth or germination of other plants surrounding the plant. However, abscisic acid promotes plant growth at low concentrations (Weston, 1976). The possibility of promoting effects of abscisic acid in the environment on growth of other plants cannot be excluded. Promotion of plant growth is also a category of allelopathy. Lepidimoide isolated from mucilage of germinated cress seeds is known as a substance promoting growth of tomato and amaranth seedlings (Hasegawa *et al*., 1992). The allelopathic effects of abscisic acid should be more deeply examined. The hormone may open a new aspect of allelopathic research.

References

Duke, S. O., Rimando, A. M., Baerson, S. R., Scheffler, B. E., Ota, E. and Belz, R. G. (2002) Strategies for the use of natural products for weed management. *J. Pesticide Sci*., **27**, 298-306.

Geary, D. R. (2002) Grass weed suppression by U.S. and foreign rice cultivars in drill seeded systems. *Abstracts of Third World Congress on Allelopathy* (Tsukuba, Japan), 71.

Hartung, W., Sauter, A., Turner, N. C., Fillery, I. and Heilmeier, H. (1996) Abscisic acid in soils: what is its function and which factors and mechanism influence its concentration? *Plant Soil*, **184**, 105-110.

Hasegawa, K., Mizutani, J., Kosemura, S. and Yamamura, S. (1992) Isolation and identification of lepidimoide, a new allelopathic substance from mucilage of germinated cress seeds. *Plant Physiol*., **100**, 1059-1061.

Ino, T. and Kato, H. (2003) Release level of momilactone B, which acts as an allelochemical, from rice plants into the environment. *Plant Cell Physiol*., **44** (suppl.), s153.

Kamo, T., Hiradate, S. and Fujii, Y. (2003) First isolation of natural cyanamide as a possible allelochemical from hairy vetch *Vicia vilosa*. *J. Chem. Ecol*., **29**, 275-283.

Kato-Noguhci, H., Tanaka, Y., Murakami, T., Yamamura, S. and Fujihara, S. (2002) Isolation and identification of an allelopathic substances from peel of Citrus junos. *Phytochemistry*, **61**, 849-853.

Leung, J. and Giraudat, J. (1998) Abscisic acid signal transduction. *Annu. Rev. Plant Physiol. Mol. Biol*., **49**, 199-222.

Toyomasu, T., Yamane, H., Murofushi, N. and Inoue, Y. (1994) Effects of exogenously applied gibberellin and red light on the endogenous levels of abscisic acid in photoperiodic lettuce seeds. *Plant Cell Physiol*., **35**, 127-129.

Weston, G. D. (1976) Effects of abscisic acid on root and shoot growth of tomato. *HortScience*, **11**, 22-23.