Gallic and salicylic acids: Sentinels of plant defence against insects

T. N. Ananthakrishnan

Localized and systemic signals are released at the site of insect feeding damage and the signals get translocated to other parts of the plant, where they induce defence mechanisms. Gallic and salicylic acids are known to play an important role in insect–plant interactions and have considerable practical application in the area of biotechnology of crop protection.

INTEGRATED pest management, increasingly recognized as a panacea for efficient pest management, has not reached the anticipated levels of success, presumably due to insufficient recognition of the chemodynamics of both insects and plants. Age-correlated changes in the composition of plants and the impact of phytochemical induction by insects and microorganisms result in altered allelochemical profiles. Increasing numbers of crop plant cultivars naturally call for more intensive approaches to a study of their chemodynamics in order to establish their susceptibility or resistance. Both as antibiotic agents against insects and pathogens and as chemical signals, secondary metabolites play an efficient role, often acting both as allomones and kairomones. Inducible systemic defences or signals give rise to a new physiological state in the target tissues which protects them from further stresses. Local acquired resistance around feeding lesions or in the vicinity of necrosis and systemic acquired resistance, detected several days after initial infection have been recognized. Enhanced synthesis and accumulation of secondary metabolites are part of an integrated defence mechanism, the same signalling mechanism triggering a whole range of responses[1]. A number of natural or synthetic compounds have been reported as inducers of systemic acquired resistance. Many of these chemical inducers tend to function as systemic signals like salicylic acid. The term 'chemical systemic acquired resistance inducer' has also been suggested[2]. Being an endogenous messenger, salicylic acid activates important secondary metabolites responsible for host resistance and is considered an inducer of pathogen-related proteins during systemic acquired resistance[3]. Speculation has been made that volatile methyl salicylate may function as an airborne signal for intra- and interplant communication[4]. Plant–insect interactions can alter the capacity of the insect to resist toxicity of many compounds and the net effect on insect performance may be altered by the diversity of the interactions. Increased recognition of chemotypes in plants consequent to behavioural diversities in insects and the additive effects of synergistic interactions often lead to multichannel defences. As such, internal driving forces in plants often lead to the diversity of secondary metabolites, resulting in the evolution of more efficient metabolic systems[5].

T. N. Ananthakrishnan is in the Entomology Research Institute, Loyola College, Chennai 600 034, India.

Role of elicitors

Plants are known to release localized and systemic signals in response to wounding by phytophagous insects. Systemic induction of resistance implies the production of a signal at the site of primary wounding or infection, the signal being translocated to the other parts of the plant where it induces defence mechanisms. Stress conditions have enabled plants to express genes, many of which encode defence proteins, enabling plant defence against insect feeding. Elicitor activity involves the activation of defence genes such as those coding for enzyme inhibitors, hydrolytic enzymes, cell-wall structural proteins and the like. Damage potential and acquired resistance in plants – whether local or systemic – contribute to the overall resistance displayed by plants in nature. Accumulation of protein can also be induced by a number of elicitors of biotic or chemical origin and salicylic acid is one of them. Secondary metabolic pathways provide versatile routes to compounds capable of transmitting information at different levels of plant organization. Esters of gallic acid and their derivatives also represent a classic case of secondary metabolism[6]. Gallic acid is located in plant tissues in the ester form and is metabolized to a glycosidic constituent. Both gallic and salicylic acids are hydroxybenzoic acids produced by the shikimate acid pathway (Figure 1). Of the numerous compounds known, cinnamic acid forms the starting point for the operation of diverse secondary metabolic processes. Hydroxycinnamic acids and hydroxybenzoic acids, among others, are essential components imparting resistance to plants and of these, gallic and salicylic acids discussed here are known to play an important role in insect–plant and plant–pathogen interactions. While gallic acid occupies a distinctive position in the overall phenolic metabolism of higher plants, salicylic acid, besides acting as a defensive chemical, also acts as a signal which moves through the plant, having the attributes of a plant hormone[7]. Induction of disease and insect resistance, enhanced growth, vigour and yield are reported after foliar sprays of salicylic acid.

Antibiotic effects of salicylic and gallic acids

In assessing the antibiotic effects of gallic and salicylic acids on the development of *Helicoverpa armigera*, studies of phenols and phenolic acids of red gram, chickpea cultivars showed the presence of gallic, salicylic and vanillic acids[8,9]. While the pupal mortality rates were high with low adult emergence rates with salicylic acid, higher rates of mortality and lower adult emergence rates were recorded with a mixture of salicylic and vanillic acids (Figure 2). The phenols and phenolic acids showed varying distribution among the different cultivars of chickpea and red gram and the degree of resistance is evident from the diversity of the developmental pattern and the malformation occurring at the various developmental stages of *H. armigera*[10]. Further, the impact of lower concentrations of these chemicals increased the percentage of parasitization and predation rates. Besides, synergistic interactions involving gallic acid have been observed to increase the effect of β-t endotoxin on *H. armigera*[11].

Similarly, gallic acid, syringic acid, resorcinol and phloroglucinol showed chronic effects on growth, ingestion and utilization of food in *H. armigera*, in relation to cotton. Survival and pupation were seriously affected, gallic acid playing a vital role, reducing growth by primarily reducing the efficiency of conversion of assimilated food. *Helicoverpa* exhibits continuous defaecation and muscular lesions of the hindgut. The impact of vanillic and salicylic acids on development, survival and adult emergence of *H. armigera* also varied greatly with concentrations tested[12]. Salicylic acid has been known to be a feeding deterrent for the phytophagous soyabean looper *Pseudoplusia includens*[13], but does not affect its growth rate. In *Nilaparvata lugens*, sucking of 0.001 M sucrose solution is almost completely inhibited by salicylic acid[14].

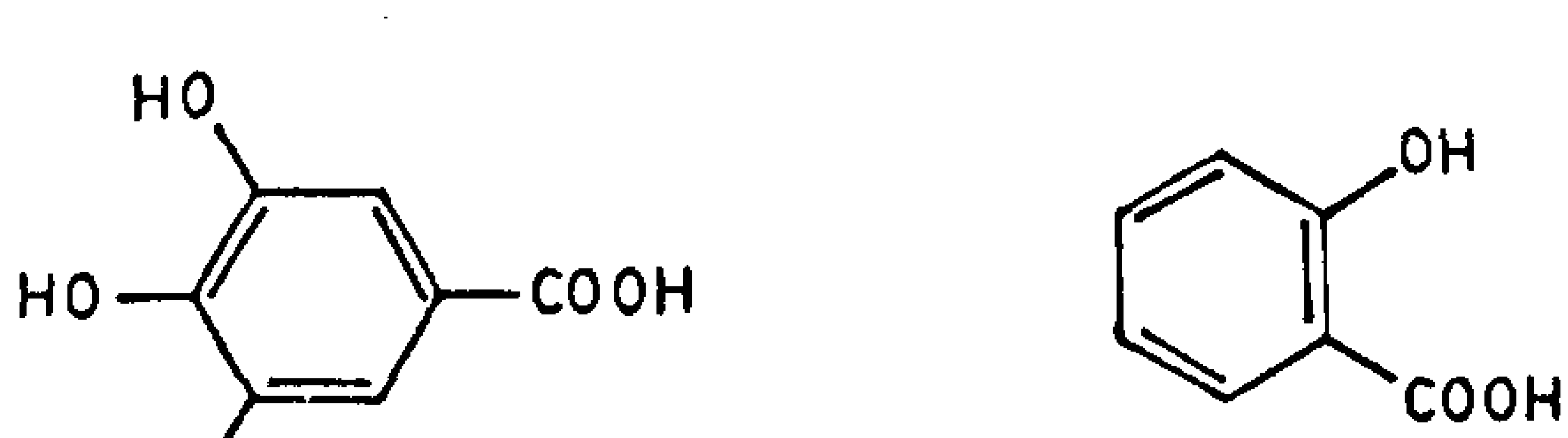
A number of plants maintain high basic levels of salicylic acid such as resistant potato variety, as also rice variety, where it may play a role in constitutive defence. That microorganisms associated with crop plants are capable of synthesizing salicylic acid is equally well known, as is confirmed by its occurrence in large amounts in the rhizosphere, imparting a protective or allelopathogenic function along with other benzoic acids[7].

Biosynthetic pathways

As for the pathway of production of salicylic acid, cinnamic acid of the shikimic acid pathway is converted to salicylic acid either via benzoic acid or coumaric acid pathway[15] (Figure 3).

Cinnamic–benzoic–salicylic acid → [healthy plant]
Cinnamic–*o*-coumaric–salicylic acid → [infected plant].

Gallic acid occupies a distinct position in the overall phenolic metabolism of higher plants and there is diversity and complexity of its ester forms. Most plants metabolize substantial quantities of polyesters of gallic acid. Gallic acid can be formed by two pathways involving shikimic acid and cinnamic acid derivatives. A myriad new compounds based on gallic acid have been isolated from plants. Metabolism of gallic acid involves the ability to synthesize esters of gallic acid with D-glucose, phenols and phenolic acids. A key intermediate in secondary metabolism is β-penta-*o*-galloyl-D-glucose and from this a pathway arises leading



Gallic acid

Salicylic acid

Figure 1. Structure of gallic and salicylic acids.

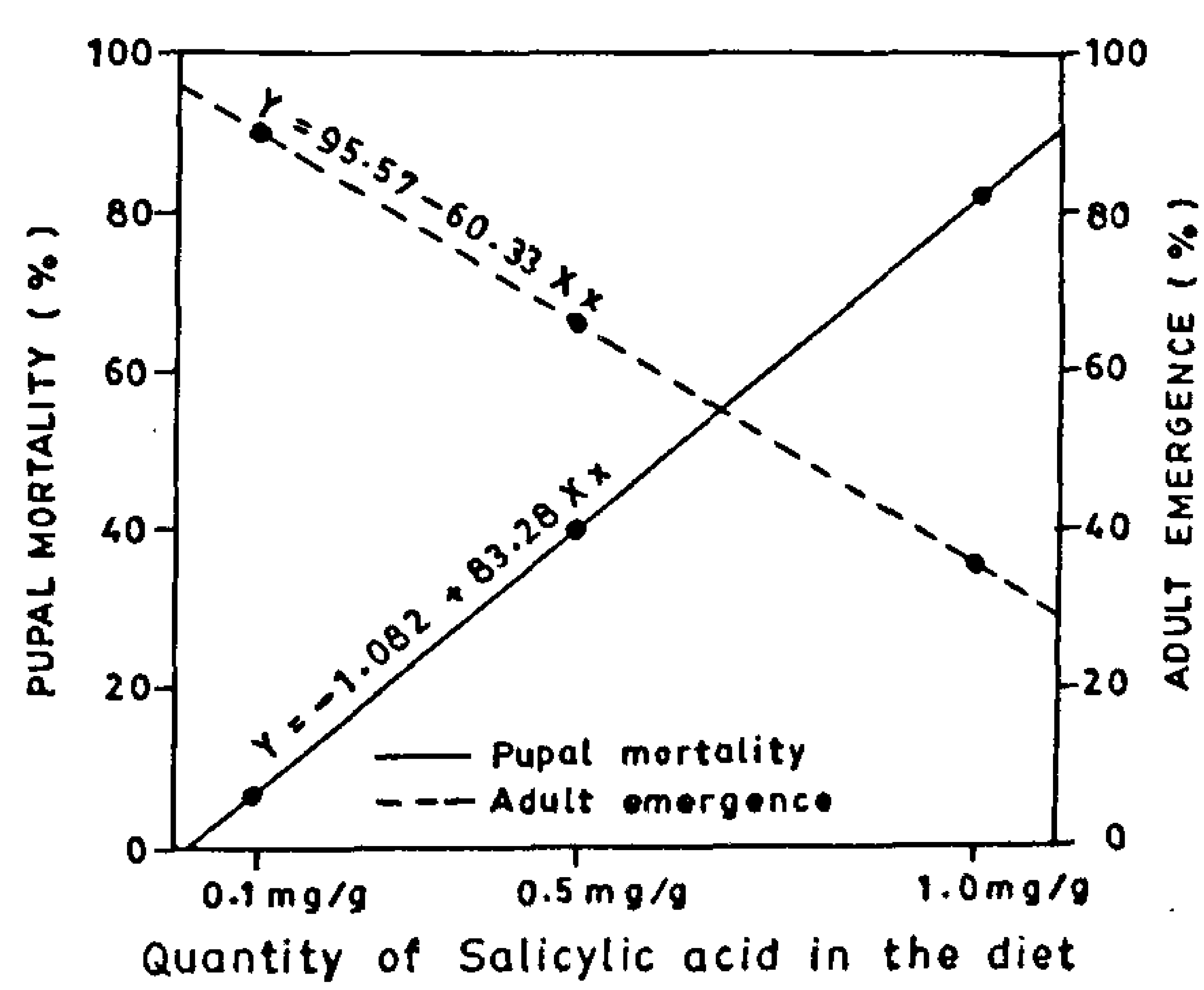


Figure 2. Percentage of pupal mortality in relation to quantity of salicylic acid in diet.

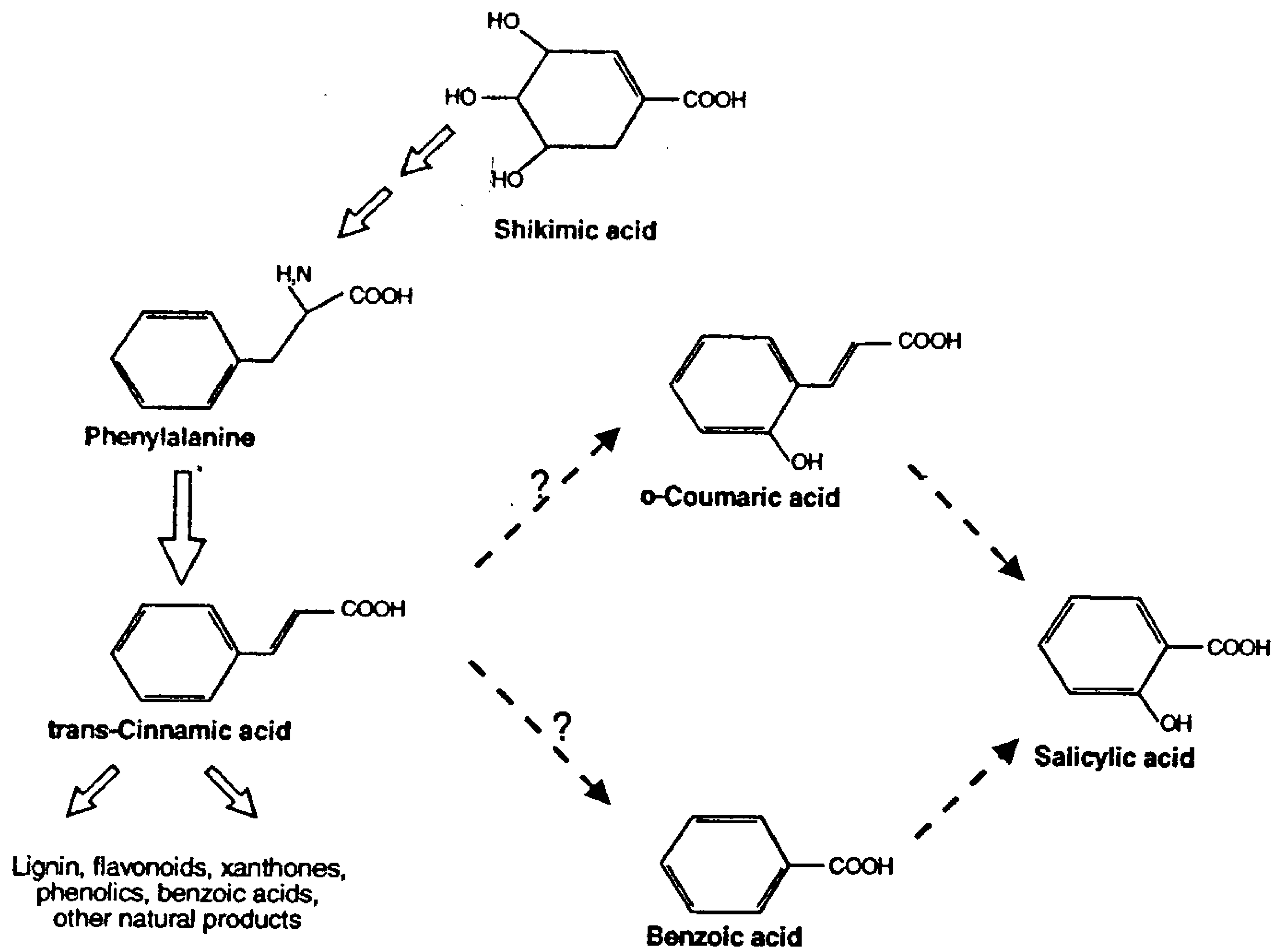


Figure 3. Pathways of production of salicylic acid.

to production of gallotannins and ellagitannins, besides hydroxycinnamic acids. Patterns of occurrence of galloyl esters exist usually juxtaposed with these forms for various hydroxycinnamic acids, more especially chlorogenic acid.

Role of tannins

Tannins represent a major barrier to insect feeding, their effectiveness being related to concentration. Hydrolysable tannins are built up from glucose and phenolic acids, especially gallic acids, while condensed tannins are polymerized flavonoids. The formation of relatively indigestible complexes with proteins reduces assimilation rates. Feeding deterrence is, however, confined more to condensed tannins. Interference with the growth of *Heliothis virescens* larva was noticed when fed on geranium leaves, geranium inhibiting growth due to the ellagic acid released[16]. Plant tannins are probably directly toxic to non-adapted insects, due to tannins binding to insect tissue in the gut. However, it has also been shown that in some polyphagous acridids, feeding was not deterred even with high levels of tannins[17]. All the same, tannins play a useful role in preventing pathogenic infections of these insects. Gallic acid being a product of tannin degradation, plays a concomitant role in antiherbivore defence.

Conclusion

The role of gallic and salicylic acids in plants and their defence functions have practical application in the area of biotechnology in crop production. In particular, transgenic plants with elevated salicylic acid levels may be the first step in the production of crops with increased resistance to insects. The question of predictability or unpredictability of herbivory is an aspect now being discussed in relation to the evolution of defence mechanisms. While there is no doubting the possible role of the action of chemical sentinels such as gallic and salicylic acids which are only two among the myriad secondary metabolites, the question of individuals expressing resistance at all times constitutively instead of being induced every time has received recent attention and to quote[18], 'induced resistance will be favoured only if the herbivory that the plant responds to is a good predictor that the plant is likely to be attacked by herbivores in the future. If the plant experiences several herbivore regimes during its life with time to respond, then an inducible strategy could be favoured'.

1. Bennett, R. N. and Wallsgrove, R. M., *New Phytol.*, 1994, **127**, 617–633.
2. Schneider, M., Sceweizer, P., Meuwly, P. and Metraux, J. P., *Int. Rev. Cytol.*, 1996, **168**, 303–341.

3. Bernays, E. A., *Host Plant Selection Phytophagous Insects*, Chapman & Hall, London, 1993, pp. 40–44.
4. Hyung-Il-Lee, Jose Leon and Raskin, I., *Proc. Natl. Acad. Sci. USA*, 1995, **92**, 4076–4079.
5. Gottleib, O. R., *Phytochemistry*, 1990, **29**, 1715–1724.
6. Haslam, E., *Plant Polyphenols*, Cambridge University Press, Cambridge, 1989, pp. 230.
7. Chessin, M. and Zipf, A. E., *Bot. Rev.*, 1990, **56**, 195–228.
8. Ananthakrishnan, T. N., Senrayan, R., Annadurai, R. S. and Murugesan, S., *Proc. Indian Acad. Sci. (Anim. Sci.)*, 1990, **95**, 39–52.
9. Ananthakrishnan, T. N., Senrayan, R., Annadurai, R. S. and Murugesan, S., *Phytophaga*, 1990, **3**, 55–70.
10. Ananthakrishnan, T. N., Senrayan, R., Annadurai, R. S. and Murugesan, S., *Proc. Indian Acad. Sci. (Anim. Sci.)*, 1990, **99**, 317–325.
11. Sivamani, E., Rajendran, N., Senrayan, R., Ananthakrishnan, T. N. and Jayaraman, K., *Entomol. Exp. Appl.*, 1992, **63**, 243–245.
12. Ananthakrishan, T. N., Daniel Wesley, S., John Peter, A. and Marimuthu, S., *Int. J. Ecol. Environ. Sci.*, 1994, **20**, 317–331.
13. Rasmussen, J. B., Hammerschmidt, R. and Zook, M. N., *Plant Phytol.*, 1991, **97**, 1342–1347.
14. Sogawa, K., *Appl. Entomol. Zool.*, 1974, **9**, 204.
15. Raskin, I., *Annu. Rev. Plant Physiol. Mol. Biol.*, 1992, **43**, 439–463.
16. Harborne, J. B., *Introduction to Ecological Biochemistry*, Academic Press, London, 1992, pp. 144–145.
17. Bernays, E. A., Driver, C. and Bilgener, M., *Adv. Ecol. Res.*, 1989, **19**, 263–302.
18. Karban, R. and Adler, F. R., *Oeccologia*, 1996, **107**, 379–385.

ACKNOWLEDGEMENTS. Thanks are due to Prof. S. S. Krishna of this Institute for discussions and to Prof. Ilya Raskin, New Brunswick for permission to adapt the figure relating to biosynthetic pathway of salicylic acid.

MEETINGS/SYMPOSIA/SEMINARS

National Conference on Industrial Engineering Towards 21st Century

Date: 31 January to 2 February 1998
Place: Tirupati

Topics include: Curriculum design; Functional applications; Research & development; Public utilities; Start-up ventures; IE tools; IE and computers; IE in rural development and micro-enterprise development, etc.; Industrial engineering and manufacturing automation; Case studies.

Contact: The Organizing Committee
IESILVER
Dept. of Mechanical Engineering
SVU College of Engineering
Sri Venkateswara University
Tirupati 517 502
Phone: 50666 Extn. 245

Symposium on Alternate Energy Materials (A Satellite Symposium of MRSI–Ninth AGM)

Date: 10 February 1998
Place: Kalpakkam

Topics include: Hydrogen storage materials; Energy options *vis-a-vis* material resources; Solar photovoltaics; Fuel cells; Thermoelectric sources; Processing–properties–performance of materials; Advanced energy management systems.

Contact: Dr Baldev Raj
Director
Metallurgy & Materials Group
Indira Gandhi Centre for Atomic Research
Kalpakkam 603 102
Phone: 04114–40234
Fax: 04114–40301, 40356, 40360

Ninth Annual General Meeting of Materials Research Society of India

Date: 11–13 February 1998
Place: Chennai

Theme seminar on advanced materials will be held in the areas of Biomaterials; Building materials; Ceramics and glasses; Composites; Electronic Materials; Magnetic materials; Metals; Polymers; Processing technologies; Thin films; Materials characterization and Fracture.

Contact: Dr U. V. Varadaraju
Chairman, MRSI
Materials Science Research Centre (MSRC)
IIT Madras, Chennai 600 036
Phone: 044–2351365, Extn. 3171, 3174, 3175, 3213
Fax: 044–2350509/2352545
e-mail: raju@msrc.iitm.ernet.in

National Conference on Recent Trends in Spices and Medicinal Plant Research and Seventh AGM of Academy of Plant Sciences India

Date: 2–4 April 1998
Place: Calcutta

Topics include: Chemistry and bioactivity of natural products; Oleoresins, aromatics, natural flavouring and colouring substances; Medicinal properties of spices; Preservation, processing and trade of spices and medicinal plants; Genetic stock identification, biodiversity and conservation; Productivity and cultivation; Micropropagation, production of secondary metabolites in tissue culture; Spices and medical plants in Ayurvedic, Unani, folk and tribal medicine; Spices and medicinal plants in rural economy; Export market, collaboration, IPR and gene patenting.

Contact: Dr Amit Krishna De
Organizing Secretary (RTSMPR)
35, Garpar Road, Calcutta 700 009
Phone: 577–2474530, 2402551