ALTERATION IN PHENOLICS DURING DEVELOPMENT OF INSECT INDUCED PLANT GALLS- A REVIEW"

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DOI: 10.5958/2455-7218.2020.00057.1

Metabolic alterations and signals compelled by pathogenic organisms stimulate certain kind of directional changes in host plant parts. Specialized galling insects like *Diptera, Thysanoptera, Hymenoptera* etc. induce highly differentiated galls on many of their host plants. The galls show not only cellular hypertrophy and hyperplasia but various differentially specialized tissues like nutritive zone, mechanical zone, cortical layers, gall chambers etc. These tissues develop as a result of not only morphogenetic factors but also due to some adaptive chemical lineages. Biochemical factors associated with these alterations include various primary and secondary metabolites, enzymes and growth regulators like auxins, cytokinins, gibberablic acid etc. Polyphenols inhibit activity of IAA oxidase and hence increases concentration of Indole 3-Acetic Acid and Indole Acetaldehyde in the developing gall tissues. As the auxin increases in gall tissues, an obvious response is cellular hypertrophy. Polyphenols settle down the activity of Reactive Oxygen Species generated during gall initiation. Polyphenols are also proved to be toxic or inhibitory to predators, parasitoids of galler species. Various studies carried out on phenolic compounds and enzymes in mite and insect induced galls have been evaluated and a comparative analysis of their impact on gall development forms the essence of the present review.

Keywords: Insect, Mite, Phenolics, Plant Galls, Polyphenols

Insect induced galls (Zoocecidia) are more or less differentially symmetrical plant tissues developed as a response to the activity of insects and mites. During the co-evolution insects used plants as their shelter, egg laying surface, as feeding entity etc. In specific cases insects preferred a particular species or family of plants for feeding or staying within them. This specificity is confined to special plant parts like leaf, stem, flower etc. in most of the cases. Gall is also known as "cecidium", and "cediology" is the branch of science dealing with "cecidia"- arises by hypertrophy of cells stimulated by egg deposition or any other activity of insects (Mites are also included in gall inducing insect group) in the review. Phytocecidia are galls on plants induced by plant parasites. Arthropod species that induce galls are called "cecidozoa", excludes extraordinary plant predators which bite the leaf by cutting, damaging or injuring tissues containing a diverse group of insects. Cecidozoa stimulate galls on different plant species, varieties and hybrids of trees, shrubs and herbs. Insect induced galls are wide spread in many arid and semi-arid regions of India (Mani 2000). According to an estimate, "the global richness of galling insects was to be approximately 120,000 species" (Espírito-Santo and Fernandes 2007), making the knowledge of this guild essential for ecological studies.

Galls offer a most suitable and protective microclimate to developing insects, if they have the ability to manipulate the structure of plant according to their requirement. This manipulation is not that easy as plants have their unique patterns of growth and development. Yet it is not that difficult for insects to induce these extremely organized or sometimes under-developed structures. Most of the galls are found during and immediately after the monsoon rains, while relatively less number of galls are reported during hot weather. This could be because of breeding time of insects is pre or post monsoon in most of the cases. But few galls are found almost throughout the year. Insects first degrade cell wall of the outer plant parts, the low molecular weight compounds functions as elicitors and as a response plant try to defend itself morphologically as well as biochemically. In few cases there are reports of successful defense against insects (Zalucki *et al*. 2001, Clissold *et al*. 2004, Zong and Wang 2007). As instance hyper-sensitive response has been observed in various willow tree varieties (*Salix viminalis*) with resistance to the gall midge *Dasineura marginemtorquens* (Hoglund *et al*. 2005).

Metabolic alterations and signals compelled by insect species stimulate certain kind of directional changes in host plant parts. The chain of alterations invariably initiates stressed regulation of gas and ion exchange. The differential coordination of morphogenetic factors (Miller and Raman 2018) with the help of biochemical factors initiates gall formation in and around the attacked area of plant part. Biochemical factors include various primary and secondary metabolites, enzymes and growth regulators like auxins, cytokinins, gibberellic acid, etc. The biochemical alterations induced by insect injury results in differential localization of metabolites in gall tissues (Hartley 1998, Konno *et al*. 2003, Singh *et al.* 2004, Shankara *et al*. 2007, Mishra *et al*. 2007). This helps meristematic tissues to differentiate in a specific way.

Role of Secondary metabolites in plant-insect interactions: Primary metabolites are important source or precursors for the synthesis of secondary metabolites. Abiotic and biotic stresses start converting substantial amount of primary metabolites to secondary metabolites. Many scientists studied interconversion of primary and secondary metabolites (Kraker and Gershenzon 2011, Kroymann 2011, Carrington *et al*. 2018). Secondary metabolites in plants provide an extensive defense against pathogens and microbes. These proved to be toxic or inhibitory to pathogens and gave greater physiological and reproductive fitness to plant. Plants containing higher amount of secondary compounds are not desirable to mankind consumption but relatively more resistant.

Secondary metabolites produced during the flowering and fruiting stages play an important role in reproduction and dispersal (Poiroux-Gonord *et al*. 2010, Frasar and Chapple 2011, Hassan and Methesius 2012). Interaction between plants and changing environmental conditions has a significant role in emerging specific natural products (Lattanzi 2013).

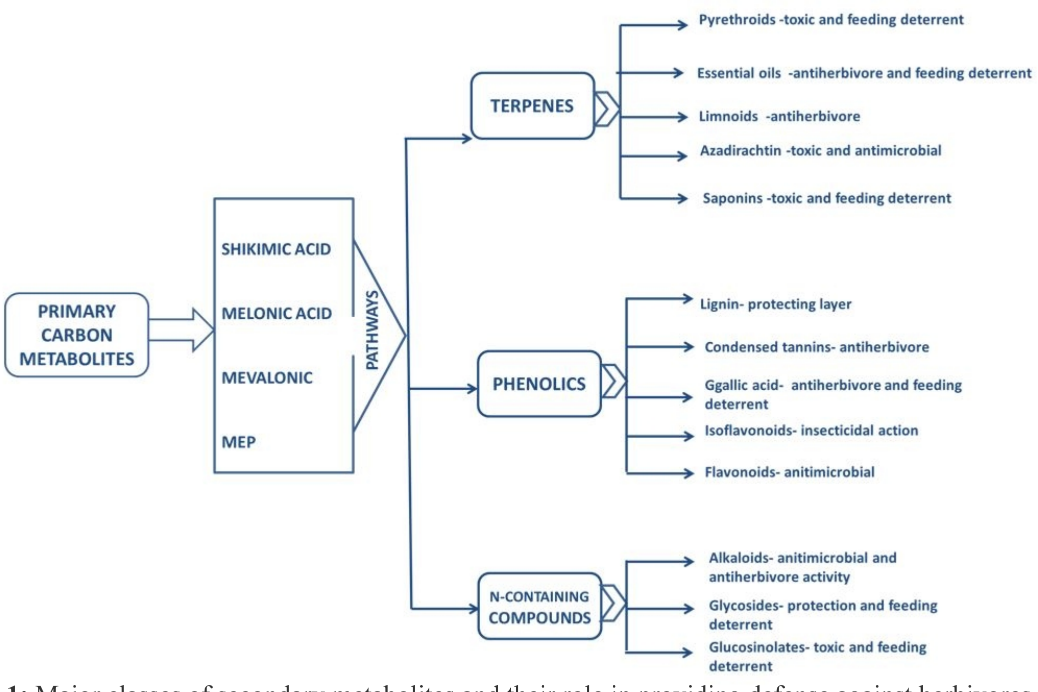

Figure 1: Major classes of secondary metabolites and their role in providing defense against herbivores

Various biotic and abiotic stresses such as high light, UV-radiations, low temperature, heavy metal, nutrient deficiency and pathogen infections etc. lead to produce more free radicals and their oxidative species in plants. In these conditions "plant increases its capacity to scavenge Reactive Oxygen Species (ROS)" (Khan and Khan 2017).

On the basis of chemical structure there are three major groups of secondary metabolites: (1) terpenes, (2) phenolics and (3) nitrogen containing compounds. Figure 1 describes major classes of secondary metabolites.

Terpenes in plant-insect interactions: Terpenes are the large group of natural product which is made up of isoprene units. These constitute an important group of secondary metabolites synthesized in plants. The compounds provide defense against herbivory and proved to be feeding deterrents to many plant feeding insects (Gershenzon and Croteau. 1990). Classes of terpenes involved in providing defense against pathogens, predators etc. include various metabolites described in Figure 1. For eg., Pyrethrins, which is a type of monoterpens, was isolated from leaves and flower of *Chrysanthemum* species and has shown striking insecticidal activity (Benner, 1993) with negligible toxicity to mammals. Essential oils and menthol are some other striking examples of monoterpenes, which are being used to prepare bio-pesticides to control insects.

Phenolic compounds in plant-insect interactions: Phenolic compounds form one of the most prominent classes of natural products in higher plants. These are frequently present in plants in an esterified state particularly as methoxy compounds. Phenols are aromatic compounds with hydroxyl group attached directly to the nucleus. These are very reactive chemical compounds and are easily subjected to oxidation, substitution and coupling reactions (Hopkins 1999). Phenolic compounds are synthesized through Shikimic acid and Pentose Phosphate pathway using phenylpropanoids compounds (Randhir *et al*. 2004). These metabolites play a significant role in plant as attractive substance to enhance pollination, coloring agent, providing defense against herbivores and showing antimicrobial activities (Acamovic and Booker 2005, Edreva *et al.* 2008). Approximately 8000 phenolic compounds have been reported from plants (Kumar and Pandey 2013).

Each plant part whether it is flower, leaf, stem, root, rhizome etc. has different type and amount of phenol and flavonoids depending on various factors (Tungmunnithum *et al.* 2018). The metabolites have hydroxyl groups which give them property to scavenge ROS generated after insect attack. Tannin, condensed tannin, gallic acid, flavonoids are some examples of phenolic compounds commonly found in plants.

Tannins are phenolic metabolites found in most of the plants with a molecular weight larger than 500 and with the ability to precipitate gelatin and other proteins from solution (Mehansho *et al*. 1987). Other phenolics may bind strongly to protein without causing precipitation. Based on their structure, tannins can be divided into two groups, (1) hydrolysable tannins and (2) condensed tannins. Hydrolysable tannins are readily hydrolyzed in alkali solutions, giving rise to a polyhydric alcohol and gallic acid, in the case of gallotannins, gives rise to ellagic acid. Hydrolysable tannins are found in plants in low amount than condensed tannins. These are present in approximately 15 orders of dicotyledon plants (Veitch and Grayer 2011). Condensed tannins can be depolymerized in hot strong acid, giving rise to anthocyanidin pigments and other products. Proanthocyanidin is an alternative name for condensed tannin. Polyphenol oxidase plays important role in the synthesis of polypehnols through the oxidation of o-dihydroxy phenols especially in plant diseases. Structure of various phenolic substances has been shown in

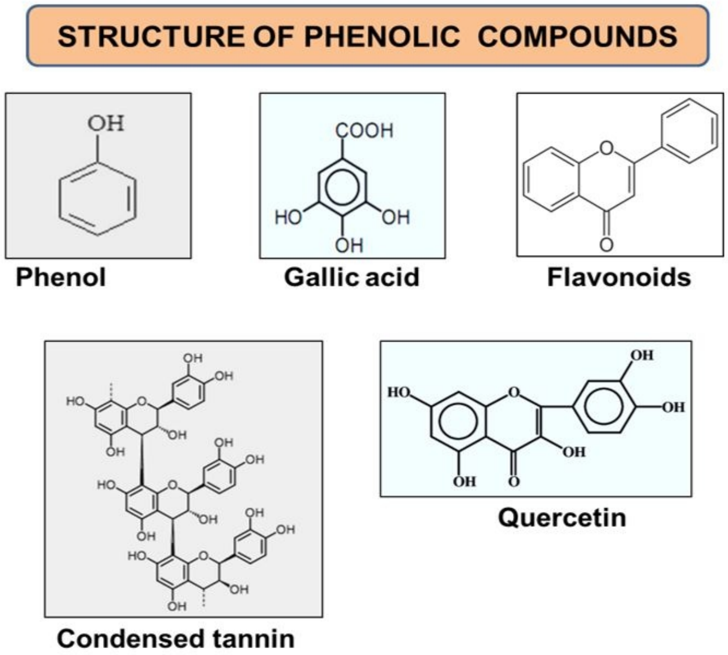

Figure 2: Structure of various phenolic compounds

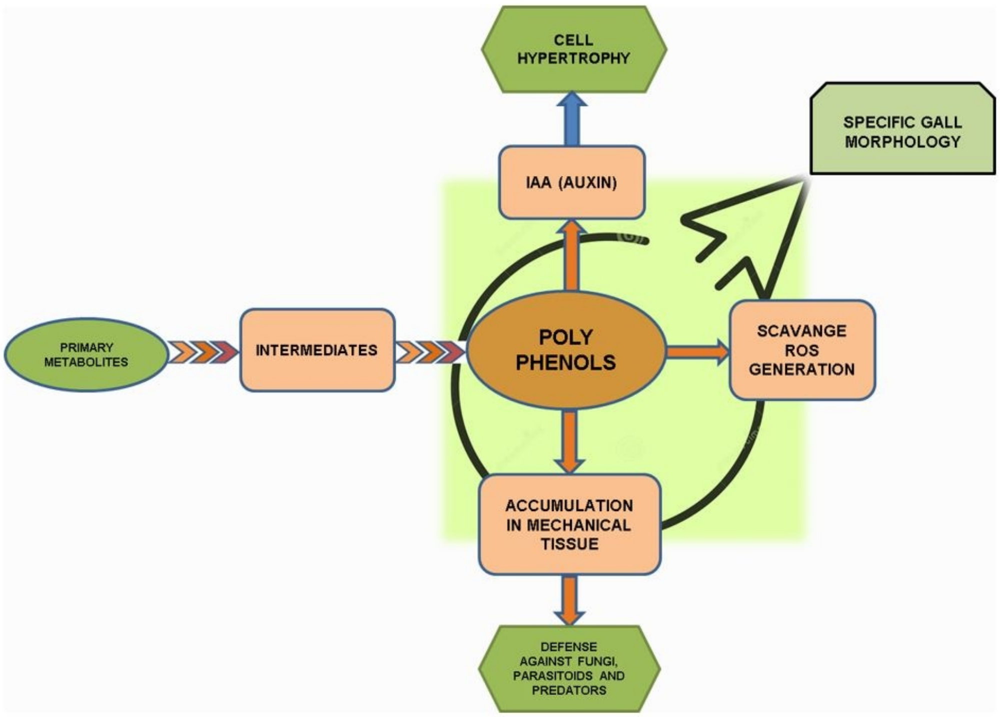

Figure 3: Role of polyphenols in plant defense: scavenging of ROS and cellular hypertrophy; each factor contributes in array of changes determining gall morphology.

Figure 2.

Flavonoids from large group of polyphenolic compounds having a benzo-γ-pyrone structure and are ubiquitously present in plants (Kumar and Pandey 2013). Recent evidence shows that "flavonoids are localized in the mesophyll cells and center of ROS generation, that is, the chloroplast" (Agati *et al*. 2012).

Phenolic compounds or polyphenols are mostly produced through the Shikimate and Phenylpropanoid pathways. Both pathways play an important role towards biotic and abiotic stresses such as the protection against solar irradiation and the robustness towards mechanical damage and in mediating defense against pathogens and herbivores. Erythrose-4-phosphate and Phospho-Enol Pyruvate (PEP) are the starting metabolites and also intermediates of Pentose Phosphate Pathway (PPP) and glycolysis. PEP reacts with erthrose-4- phosphate through the phenylpropanoid pathway and generates phenolic compounds. Through Shikimic acid pathway it also produces phenylalanine.

According to Figure 3 the very first response after the attack and recognition of pathogen is formation of ROS. After some time when insect controls the host's morphogenetic factors and metabolic responses it has to overcome or settle down the ROS generated. Polyphenols are mostly found accumulated in gall tissues but not very near to the galling insect. Polyphenols have been recorded in mechanical zone present on the outer side of the developing gall (Mishra *et al*. 2007). In mechanical zone deposition of maximum amount of polyphenols suggests protection of eggs and larvae of galling insects against parasitoids, fungi and other predators. On the other hand polyphenols inhibit activity of IAA oxidase and this increases concentration of Indole 3-Acetic Acid and Indole Acetaldehyde (Zhao 2010) in the developing gall tissues. As the auxin increases in gall tissues, an obvious response is cellular hypertrophy (Oliveira and Isaias 2010). Polyphenols also settle down the activity of ROS generated earlier (Pasqualini *et al*. 2013).

Nitrogen-containing compounds in plant-insect interactions: Alkaloids, glucosides and non-protein amino acids are included in nitrogen containing secondary metabolites. These secondary metabolites are mainly derived from amino acid precursors. Alkaloids and glucosides show medicinal properties and hence beneficial to mankind, but at higher concentrations toxic too. Most of the alkaloids are present in alkaline medium in plants as the name suggests. Examples of some most important alkaloids are nicotine, morphine, caffeine etc. which have given the all due economic value to the plants. Anti-aging studies on galls of *Terminalia chebula* showed higher antioxidant and free radical scavenging activity not only from the cell proliferation stimulation, but also from the phytochemicals existing in the extract of this plant including alkaloids, flavonoids, tannins and xanthones (Manosroi *et al*. 2010).

Glucosinolates, N-containing secondary metabolites are volatile toxins and feeding deterrent to insects. These give specific odor to plants of Brassicaceae family specially Mustard (*Brassica* spp). It breaks into other smaller defensive substances. Volatile compounds are important for recognition of host plants and gall induction (Ferreira *et al*. 2019).

Antioxidant activity and phenolics: Free radicals are formed from molecules via the breakage of a chemical bond such that each fragment keeps one electron, by cleavage of a radical to give another radical and, also via redox reactions (Dröge 2002). Oxidative stress plays a major part in the development of chronic and degenerative ailments such as cancer, arthritis, aging, autoimmune disorders, cardiovascular and neurodegenerative diseases in human beings (Pham-Huy *et al*. 2008). ROS in living organisms is stimulated by numerous abiotic and biotic stresses. Antioxidants are tremendously important substances which possess the ability to protect the body from damage caused by free radical induced oxidative stress (Mahdi-Pour *et al.* 2012). Phenolic and flavonoid compounds derived from plants were proved to be potent antioxidants and free radical scavengers (Sugihara *et al.* 1999). Phenolic compounds possess many hydroxyl groups and effective hydrogen donors, which make them good antioxidants (Rice-Evans *et al.* 1995).

Phenolics in mite induced galls: Zoocecidia are mainly induced by two major groups of cecidizoa (i) Acarina (ii) Insecta. Acarina includes mainly two families of mites showing cecidogenous activity (a) Eriophyidae (b) Tarsonemidae (Meyer 1987). Initially 500 gall inducing species of Eriophyidae were recognized (Mani 1964). Galls caused by mites (Eriophyidae) are usually small in size, sometimes large bud like, blisters, leaf rolling, stem and foliar deformation like. Around 3,700 species of mites have been recognized on various species of higher plants (Amrino *et al.* 2003). In North India major groups of plant feeding mites (phytophagous mites) are spider mites (tetramychidae: about 106 species), false spider mites (Tenuipalpidae: about 98 species), gall or bud mites (Eriophyidae: about 485 species) and yellow or broad mites (Tarsonemidae: about 10 species) by Singh and Raghuraman (2011). A total number of around 2670 phytophagous mites had been estimated in 2010 under a project (Singh and Raghurama, 2011). Krishnan *et al.* (2011) recorded that out of total plant galls studied in area of Tamilnadu 20.75% were mite induced. *Eriophyes* mite's body is slightly tapered toward the posterior end with two pair of legs and two pair of mandibles. According to a model proposed by Thomsen 1988 eriophyoid mites ejects saliva onto the surface of leaf and digest cuticle and cell wall enzymatically. Phytohormones present in saliva are secreted into epidermal cells and initiate further abnormal growth and development of plant tissues (Petanovic and Kielkiewig 2010). In 1cm^2 leaf area, ratio of total phenolic compound increase from 3:1 in control to 5:1 in infested leaves in a susceptible apple cultivar was recorded due to mite infestation (Kozowski 1997). Mite uses plant parts superficially and as a response phenolics increases in parts away from the attacking sites. There is a pattern of gall formation where blisters and plain surface area on leaf are both alternating each other. In case of *Eriophyes tetanothrix* induced galls on *Salix caprea* phenolics were recorded more in mature galls in comparison to ungalled leaf tissues (Hartley 1998). Hartley (1998) experimentally concluded that gall tissue is distinct from plant tissue because of differential rates of synthesis of phenolics between gall and surrounding plant tissues. Eriophyoid galls on *Quercus leucotrichophora* showed higher accumulation of tannins (Mishra 2008) and high amount of condensed tannins, gallic acid etc. in comparison to healthy leaves (Patni *et al.* 2012).

Phenolics in insect induced galls: Specialized galling insects like Diptera, Thysanoptera, Hymenoptera etc. induce highly differentiated galls on host plants. The galls show not only cell hypertrophy and hyperplasia but various differentially specialized tissues like nutritive zone, mechanical zone, cortical layers, gall chambers etc. Figure 4 shows different types of leaf galls found on trees like *Ficus*, *Madhuca*, *Quercus*, etc. These tissues develop as a result of not only morphogenetic factors but adaptive chemical lineages. Primary metabolites are mostly found accumulated near the site of incidence and where egg and/or larvae are present suggest zone gives nutrition to developing insects.

There is a well established debate on whether galling stimuli comes from insect or it is already present in host tissues? The most

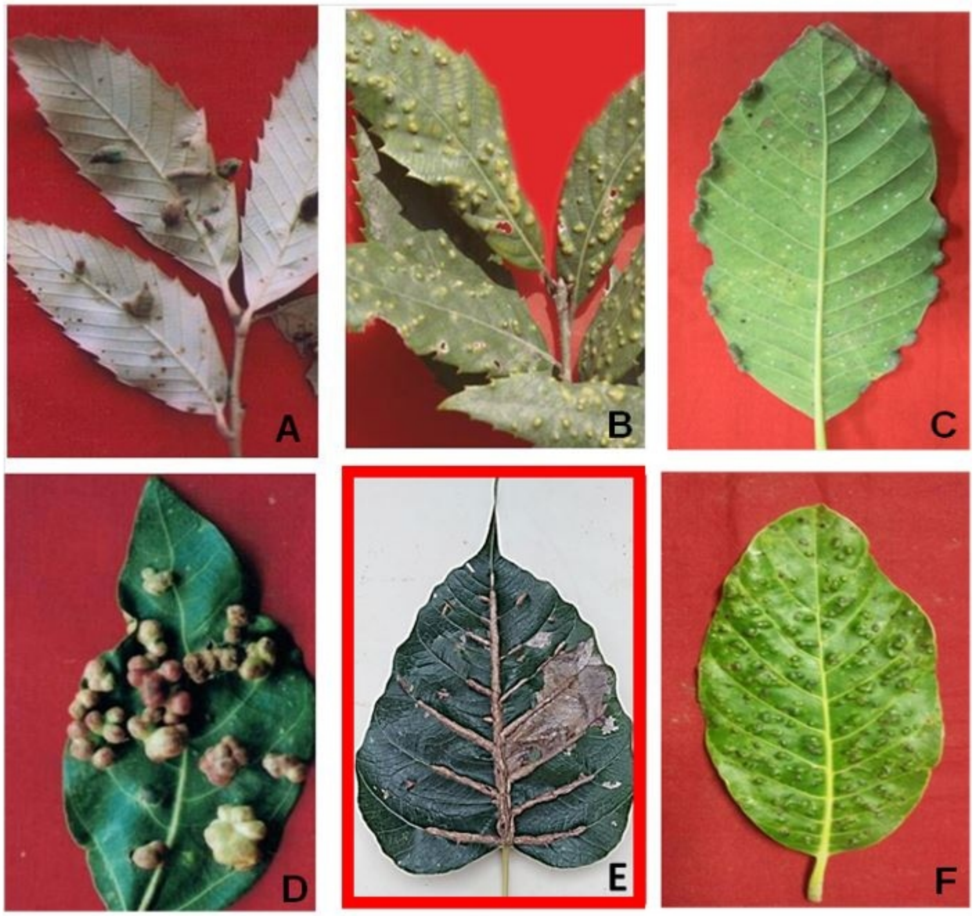

Figure 4: Different types of leaf galls on various tree species **A**. Pouch gall on *Quercus*, **B.** Blister gall on *Quercus*; **C.** Marginal roll gall on *Madhuca*; **D.** Profused galls on *Ficus.* **E.** Vein galls on *Ficus religiosa*, **F**. Blister galls on *Madhuca* (source: Mishra and Patni 2008b, Kumkum *et al*. 2020)

commonly proposed signals in the development of plant galls are plant growth factors, such as indole acetic acid (IAA) and other auxins, and/or zeatin and other cytokinins, or synergists thereof (Cornell, 1983, Shorthouse and Rohfirtsch 1992). Polyphenols have been given an equal importance which can be camouflaged by insects in secretions to develop new tissues in host plants. Polyphenols like gallic acid, catechin and epicatechin performed protective role to auxins in delaying or inhibiting activity of IAA oxidase (Mendez and Mato 1997). The physiology and histochemistry of insect and mite induced galls have been studied (Kant and Ramani 1988, Patni *et al*. 2000).

Bedetti *et al.* 2014 concluded in their work that phenolics control auxins in galls. They also suggested that ROS, phenols, flavonoids, IAA localized more in gall tissues". Phenylalanine Ammonia Lyase (PAL) and Tyrosine Ammonia Lyase (TAL) regulate the biosynthesis of a wide range of secondary compounds, including lignin, flavonoids, furanocoumarin (Heldt and Piechulla, 2011) and isoflavonoid phytoalexins and wound protectant hydroxycinnamic acid esters. Plant PAL and TAL activity can be induced by pathogen attack and by environmental stresses such as wounding and light (Harlbrock and Scheel 1989). "Increasing PAL and decreasing TAL activities in stem and rachis gall tissues of *Prosopis cineraria in vivo* and *in vitro* were recorded" by Ramani and Kant (1987). PAL and peroxidase activity increased rapidly in tomato leaves treated with *Quercus infectoria* gall extract (Yamunarani *et al*. 2005). This is significant to mention that phenolics accumulation in gall tissues is not due to passive transport, it is due to their biosynthesis in gall tissues (Hartley 1998).

Aphids, belonging to hemiptera group of insects, have been considered specialist gall inducers. Most of the aphids are crop pests and considered as important viral vectors in crop plants. Their position in inducing galls is next to Cecidomyiidae (Diptera), Eriophyoidea (Acari), and Cynipoidea (Hymenoptera) with special reference to Indian subcontinent (Mani, 2000). "Aphids exhibit social behavior in colony defense and gall repair, symbiotic relationship between different organisms in galling is quite rampant' (Patel *et al*. 2018). Out of the 76 gall-inducing aphids known in the Himalaya, "70 species occur in the Western Himalaya, 27 in the Northwestern Himalaya, 27 in the Himalaya, which is part of Pakistan" (Chakrabarti 2007). In study on Himalayan aphids, with the increase in solubilization of nutrients, a simultaneous increase of phenolics in gall tissues also occurs during the growth of the galls and the aphids (Chakrabarti & Chakrabarti 1985, 1990).

Psyllids (Hemiptera) are host specific sucking insects forming different kind of galls on a wide spectrum of vascular plants (Yang *et al*. 2006). Galls induced by Psyllid mainly act as sink of nutrients for gallers and in most of the cases are not differentiated much. According to Mapes and Davies (2001) in galls of *Solidago altissima*, IAA concentrations were the highest in the early stages and decreased along the developmental phases. Dimorphic galls have also been reported. *Prociphilus himalayensis* (Hemiptera) first induces 'leaf-curl galls' and later 'leaf-fold galls' are induced on *Lonicera quinquelocularis* (Banerjee & Chakrabarti 1993). Mostly simple parenchyma/ cortex tissue of gall does not contain higher amount of secondary metabolites but gall tissue of *Schinus polygamous* upon response to psyllid *Calophya* leads to formation of phenolic compounds in parenchyma (Guedes *et al*. 2016). These compounds favor the invader in many ways.

Eshwarppa *et al*. (2015a, 2015b) reported higher antioxidant or ROS scavenging activity in gall extracts of *Ficus glomerata* (induced by homopteran *Pauropsylla depressa*) and *Terminalia chebula* can be correlated with higher phenolics and flavonoids in gall extracts.

Gall inducing Cecidomyiid (Diptera, Insecta) are highly species specific group of insects. Dipteran larval development mostly takes place inside the gall cavity for example *Dasineura*, *Hartigiola*, *Rhabdophaga* etc. (Meyer 1987). Few of these insects form highly differentiated pouch and roll galls on plants. Cecidomyiidae is the largest family inducing differentiated galls and also known as gall midges. These are mostly monophagous or oligophagous species inducing galls on one or few host species in a single genus respectively (Carneiro *et al*. 2009). Increasing activities of phenolics, condensed tannins, PAL and TAL in the developing gall tissues of *Quercus leucotrichophora* induced by cecidomyiid were recorded (Mishra and Patni 2008a). Sclerenchyma localized with tannin and phenolics is a special feature of some of Dipteran galls.

Sawflies induced galls consist of rapidly growing undifferentiated cells (Meyer, 1987). Four genera of Galling sawflies (Hymenoptera): (i) *Euura*, (ii) *Pontania*, (iii) *Eupontania*, (iv) *Phyllocolpa* (Zinovjev and Vikberg 1998) mainly form galls on plants. These galls vary in shape and size from open, fold, roll or closed galls. Nyman and Titto (2000) studied phenolics and their role in six *Pantania*-Willow gall systems. Some phenolics that are virtually absent from host leaves can be found in galls. Gall interiors contained low molecular weight phenolics than leaf tissues (Nyman and Titto, 2000). This supports the nutritive hypothesis where gall interiors are mainly to provide nutrition to developing galler. This clearly infers that galler insects determine the location, size and shape of galls (Stern 1995, Crespi and Worobey 1998; Stone and Cook 1998, Nyman *et al*. 2000) at later stages by regulating physiology of host plant. No connection has been found between galler phylogeny and host plant chemistry in the few studies that have addressed the question (Roininen *et al*. 1993, Nyman *et al*. 2000).

In young and mature leaves of five oak species (*Quercus leucotrichophora, Q. semicarpifolia, Q. serrata, Q. ilex, Q. glauca*), condensed tannins have been evaluated by Makker and Singh (1991). It suggests that in oak trees which already contain high levels of polyphenols, activity of insect species elevate these levels to many fold. TLC, HPLC, and IR spectral studies confirmed the presence of gallic acid in Dipteran leaf galls in *Q. leucotrichophora* in comparison to normal leaf (Patni *et al*. 2012). "Elevated concentration of condensed tannins have also been found in galls induced by cynipid wasps" (Cornell, 1983), thrips (Ananthakrishnanan and Gopichandran, 1993), cecidomyiid midges (Yang *et al*. 2003).

Phenolics (Total phenol, condensed tannin and gallic acid) and oxidative enzymes (peroxidase, polyphenol oxidase, PAL and TAL) were found more in various leaf galls as compared to healthy leaves (Stonier 1972, Ramawat, *et al*. 1979, Ramani and Kant 1989, Vyas 1989, Singh *et al*. 2005, Mishra 2008). Elevated levels of gallic acid in various galls of *Madhuca longifolia* have been reported by Kumkum *et al*. (2020). In some galls after removal or death of larva from gall chamber, tissues start accumulating secondary metabolites, phenolic substances and variety of minerals (John and Shorthouse 2000; Florentine *et al*. 2005).

These elevated levels of polyphenols and related compounds in various gall tissues studied and proved experimentally, clearly suggest their significant role during development of galls. After initiation and accepting elicitors from galler insect many biochemical lineages initiate in the host plant. Simultaneously host plant also starts defense against alien organism. Plant galls' morphology shape and size not only depend on the insect stimulus, but also depends on hosts' biochemical profile and existing defense strategies. Specialized galls are a comprehensive result of insect stimulus and host response to this.

Economic importance of insect induced plant galls: Plants upon invasion and gall initiation by insects produce various proteins, carbohydrates, secondary metabolites in hypertrophied tissues. Some of these proteins block pest voltage gated calcium channels (Herzig and King 2015). In this process, newly synthesized, enhanced or accumulated compounds in gall tissues have sometimes proved to be useful for mankind. Galls in different geographical regions are consumeds as food or medicinal purposes (Kant 2000). The dried excrescences of *Terminalia chebula* galls are frequently sold at markets in Southeast Asia and used in medical applications as anti-aging and imparting longevity as well as boosting immunity (Zhu 1998, Lemmens and Bunyapraphatsara 2003). Antioxidant potential of galls of *Quercus infectoria* has been evaluated by Umachigi *et al*. (2008).

Oak (*Quercus*) galls contain high concentrations of gallic and tannic acid, which are being widely used in manufacturing medicines and permanent inks. The Aleppo oak gall of Asia Minor, produced by a cynipid wasp, contains about 65 percent tannic acid, which is being used in making best permanent inks for centuries (Elmer 2018). Galls of *Quercus leucotrichophora* tree commonly found in Himalayan region give brown and are camel colour with alum and iron mordants and used in dying silk and cotton fabrics (Mishra and Patni 2011). The consequent solar drying, soap washing and heating did not alter the colour developed during the dyeing process extracted from *Zizyphus* gall (Gopi 2004).

The gall extract of *Wisteria floribunda* from the Fabaceae family is used to treat tumors in Oriental medicinal practice (Patel *et al*. 2018). Various pharmaceutically important compounds like phenols, flavonoids, steroids, triterpenes, tannins, saponins and alkaloids have been identified in *Rhus* and *Quercus* galls (Upadhye 2010). Experimentally these galls have been proved to be anti-inflammatory, antibacterial and useful in female health issues, (Shrestha *et al*. 2013, Shrestha *et al*. 2014). Similarly various leaf galls caused by aphids are used as anti-inflammatory, antiasthmatic, antipyretic, blood cleanser, antimicrobial, antioxidant etc. (Uddin *et al*. 2012a, 2012b; Ullah *et al*. 2014; Eshwarappa *et al*. 2015a, 2015b)

CONCLUSION

Insect and mites have been inhabiting plant tissues since long time to feed, oviposit, chew etc. The attack induces various morphological as well as biochemical signals to combat the unwanted condition under defense mechanism. Biosynthesis and accumulation of a wide range of secondary compounds, including phenolic compounds is significantly recorded by a number of scientists working in the field. Elevated concentrations of condensed tannins, gallic acid, tannins, PAL, TAL, flavonoids, etc. have been found in gall tissues, which are correlated with specialized biochemical lineages other than healthy plant parts. The altered profile of phenolics in galls suggests their significant role during development of galls. Plant galls' morphology shape and size not only depend on the insect stimulus but also on hosts' biochemical profile and existing defense strategies. Specialized galls are therefore enriched with metabolites which could be economically important for antioxidant, antimicrobial, antipyretic, anti-inflammatory activities.

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