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Gall diversity, causal agents, their adaptive significance and gall infestation in sericultural host plant

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Abstract
A gall is a growth of plant tissue that starts with the chemical and/or mechanical stimulus of an organism, which increases the production of plant growth hormones. An insect gall forms due to the response of plant to the insect life cycle – starting from egg laying up to adult emergence from the gall. The host plants of silkworms play a very crucial role for the production of raw silk whereas on the other hand the nutritional value of food plants are the possibilities of obtaining good cocoon crop. One of the important yield factors affecting the yield of the silk is the attack of insect pests on silkworm. Among the various insect pests, the gall insect damages the leaves and tender parts of the stem of some host plants by forming galls. Galls are infested by gall midges, gall wasps, aphids, psyllids and phylloxerans. There are also some of the gall forming species which were found in different host plants of silkworm.

Keywords: Galls, gall insects, adaptive significance, silkworms, host plants

Introduction
Insects are one of the most evolved groups of organisms as they are well adapted to almost all habitats, even inside plants or animal tissues. Plant galls represent a unique and complex inter-specific interaction between the inducer organism and the host plant. Insect galls are one such curious wonders of nature that attracts the attention of many naturalists. Galls are simply pathologically developed cells that have proliferated in a region of the plant, causing an external swelling or modification of the plant as a result of parasitic organism [1]. Systematic study of galls appears to have started with the investigation by the great Italian biologist Marcello Malpighi in the 17th century. Galls are rich in resins and tannic acid and many other plant secondary metabolites and are used in the manufacture of drugs, dyes, ink. Galls arise as the result of an inter-specific association between a host plant and an insect. Gall inducers are distinctive in that they actively manipulate the host plant through mechanical and or chemical stimuli to form a structure which provide the inducer with both nutrition and shelter [2]. There are approximately 13,000 species of insect gallers known in the world [4, 30]. Gall inducers have evolved independently in seven insect orders with most prominently seen in aphids (Aphididae, Homoptera), midges (Cecidomyiidae, Diptera), sawflies (Tenthredinidae, Hymenoptera) and cynipids (Cynipidae, Hymenoptera) [31].

Gall producing agents
The various agents that have been reported to act as biological incitants of tumorous growth in plants can be classified as follows:

Virus: Abnormal plant growths induced by viruses. Sweet clover root tumor is a well-studied example.

Bacteria: Bacteria induce plant tumors and most common example is crow gall tumor induced by *Agrobacterium tumefaciens*. It is one of the experimental models in the field of plant tumor physiology.

Fungus: Fungi also induce galls on various plant organs. Root galls on *Brassica campestris* Linn. is an example.

Nematodes: Many round worms were also reported as gall inducers especially root galls. Root galls on *Abelmoschues esculentus* (Linn.) Goodey is one example.

Mites: The gall inducing acarines mostly belong to the family Eriophyidae and lesser extent to the Tenuipalpidae. Maple Spindle Gall is a common example.

Insects: Gall inducing capacity exists in diverse insect orders including Thysanoptera, Hemiptera, Diptera, Hymenoptera, Lepidoptera and Coleoptera.

Major gall producing families under class Insecta

a. Thysanoptera: Thrips are mostly phytophagous (feeding on plants) or mycophagous (feeding on fungal mycelia or spores). Thrips induced galls vary from irregular proliferation of plant tissues to highly organized structures [3]. Leaf gall of fig caused by *Gynaikothrips uzeli.* is a standard example.

b. Diptera: "The family Cecidomyiidae (gall midges) is one of the most species rich families of Diptera and also contains the largest group of gall inducing insects in the world". From India, 394 species of gall midges under 125 genera belonging to three subfamilies are reported. On a global scale in addition to the family Cecidomyiidae, few gall inducers were also reported from family Tephritidae and Chloropidae [4].

c. Hemiptera: The gall induction property in Hemiptera can be seen in scale insects, aphids, and psyllids. Gall inducing taxa in Psylloidea occur in all of the families including Triozidae, Phacopteronidae and Calophyidae [5]. Gall inducing coccid family, Beesonidae is associated with host plants of the family Dipterocarpaceae. "Aphids induce very less number of galls globally; no more than 10% of the 4401 species are confirmed gall inducers" [6]. Several species of non-galling aphids occur commonly in peninsular India, whereas no gall-inducing aphid is known in this region.

d. Hymenoptera: Gall inducing hymenopterans (gall wasps) include cynipid wasps (Cynipidae), fig pollinating wasps (Agaonidae), saw flies (Tenthredinidae) and few members from Chalcidoidea. In India, saw fly and cynipid induced galls are confined to the slopes of Himalaya [25].

e. Lepidoptera: Relatively few lepidopterans induce galls. A total of 179 lepidopteran gall inducers are identified globally belonging to 20 families. Fifteen gall inducing lepidopterans are reported from India [26]. *Betousa stylophora* (Swinhoe) causing stem galls on *Emblica officinalis* Gaertn. is a common gall found throughout India [27, 28].

f. Coleoptera: Very few insects under this order have gall inducing capacity. The only taxon of Coleoptera recognized as gall inducing species is the subfamily Ceutorhynchinae of Curculionidae. Little is known about the gall inducing coleopterans of the Orient [29]. *Baris cordiae* Marshall is an example for coleopteran galls, on the leaf and petiole of *Cordia myxa* Linn [26].

Types of galls

Based on Gall Morphology [1] galls are classified as follows.

1. Filz galls: Galls consisting entirely of more or less extensive and excessively developed epidermal hairy out growths. Filz galls are the simplest gall in which the gall maker is mostly external, and are often caused by species of eriophyid mites.

2. Fold and roll galls: The margin of the leaf blade is folded or rolled more or less completely, either upward or downwards, associated with greater or lesser swelling of the affected part. Leaf fold and roll galls are mainly caused by gall inducing thrips.

3. Pouch galls: "It arises from a localized intense out-arching of the leaf blade, producing a bulging on one side and a corresponding invagination on the other side. It is hollow as the name indicates; the gall cavity contains the cecidozoa. In covering gall, the externally situated cecidozoa induces the pathological tissue to grow around, so that eventually it comes to be enclosed within the gall."

Based on the site of infection [3] galls are classified as follows

1. **Blister gall:** Blister-like swellings of leaves
2. **Bud gall:** Deformities in buds
3. **Bullet gall:** Nearly solid, unicellular or monothalamous galls Looks like bullets
4. **Cecidomyia:** General term applied to any species referring to gall midges
5. **Erineum:** Hairy or pile-like by plant mites
6. **Flower galls:** Deformed flowers or masses of flowers
7. **Fruit galls:** Deformity on fruits and seeds
8. **Leaf galls:** Deformations with leaves
9. **Leaf spots:** Marked discoloration rather than swellings or deformation
10. **Oak apples:** Term used for particular familiar large galls on oaks of genus *Amphibolips*
11. **Pouch galls:** Simple, pouch-like deformities
12. **Roly-poly galls:** Loose, usually oval cell with a large cavity
13. **Root galls:** Galls on roots of plants
14. **Rosette galls:** On bud tip. Generally, consist of central cell surrounded by a rosette of partly developed leaves
15. **Stem or twig galls:** Deformations on twigs and stems
16. **Subcortical galls:** Galls just under the bark of (usually) one side of stem or twig. Irregularly shaped

Gall development stages

The development of galls has four distinct phases: induction, growth and differentiation, maturation, and dehiscence [4, 7].

The induction phase is characterized by a sequence of events that define the recognition of the oviposition site (tissue, organ, and host plant), and the behavior of the inducing insect. It is a critical stage, and events during oviposition and/or feeding promote crucial changes in the tissues of the host plant. Generally, the galling larvae require a reactive, meristematic tissue for the formation of galls [1, 4, 8].

The phase of growth and differentiation of the gall is the period in which its biomass increases remarkably due to the increased number of cells—hyperplasia (cell division) and/or hypertrophy (increase in cell size). Both hyperplasia and hypertrophy are defined by the feeding activity of larvae, whose saliva seems to modify the cell wall and dissolve cell contents. The activity then defines the form of the larval chamber, and possibly the external shape of the gall [9].

The maturation phase of the gall occurs when the insect is in its last instar. This is the main tropic phase of the gall inducer,

and that is the time when it eats an expressive mass of nutritive tissue. Then, the inner cortex will disappear under the control of the inducer, and the outer cortex of the gall, which is more under the influence of the plant [4], will have its resources totally drained.

Finally, the stage of dehiscence or the opening of the gall occurs at the end of the maturation phase, when the greatest physiological and chemical changes occur in the gall tissues. By the end of this phase, the flow of nutrients and water stops.

Adaptive significance

The effect of gall structure and the associated insect on the plant have some adaptive significance which was described by 4 hypotheses –

1. The hypothesis of the adaptive value of galls for the plant
2. The nutritional hypothesis
3. The enemy-free hypothesis
4. The micro environmental hypothesis

According to the hypothesis of the adaptive value of galls for the plant, galls should limit the movement of the insect, restricting it in space and time, and thus, the gall structure should be just a defensive structure. Most of the evidences do not support this hypothesis since galls act as sinks, translocating nutrients from other plant parts and limiting the growth and reproduction of host plants. Several lines of evidence illustrate the impact of galls on the fitness of their host plants [10, 11]. Three other hypotheses advocate that the gall should present an adaptive value for the insect: the nutritional, the enemy-free space, and the micro environmental hypotheses [12].

The nutritional hypothesis is supported by several studies that show that the galling insect is able to manipulate the host plant, inducing the formation of a nutritionally superior tissue in comparison to the other non-galled tissues of the host plant [9, 13]. This nutritive tissue is also free of defensive secondary compounds [12, 14, 15]. Studies on galls induced by tenthredinids on species of willow (*Salix*) in the United States showed that defensive substances, mainly phenolic compounds, are common in the outer cortex of the galls, suggesting that the insect can benefit from their defensive properties against other insects [14, 16, 17].

The enemy-free hypothesis argues that galling insects are less predated and/or parasitized when compared with other phylogenetically close insects, but with a different feeding habit. For example, galls induced by tenthredinids are attacked by fewer parasitoid species and have lower mortality rates than free-living ones [18].

The micro environmental hypothesis states that because galls are sessile and protected by their structure, the galling larvae are less susceptible to abiotic environmental changes, particularly temperature and humidity. Hygrothermal and nutritional stress, defined here as high temperature and low humidity, and nutritional quality of the plants [19] should be the crucial environmental factors acting on the selective evolution of galling insects. Recent studies support the assertion that galling insects are richer in species and more abundant in hygrothermal and nutritionally stressed habitats, with sclero-phyllous vegetation in tropical and temperate regions [20].

Gall Infestation in Silkworm Host Plants

1. Gall infestation in Tropical Tasar silkworm host plants

(a) Asan (*Terminalia tomentosa*)

Family- Combretaceae

Gall causing agent – *Trioza hirsutae* (Homoptera, Psyllidae)

The galls of *Trioza hirsutae* are leaf roll, epiphyllous, in rolling of two margins towards the midrib, irregularly swollen, twisted, glabrous, pale green, sometimes pinkish also. Size of newly formed gall varies from 2-6 cm in length and 1-2 cm in width. Minimum 6.67% infestation occurs in April and maximum 75- 93.75% occurs during late August to October due to favourable conditions. Generally, galls occur on the entire foliage of young plants but on a mature tree, maximum galls are found in the middle area of the tree foliage while minimum on the bottom and canopy of tree foliage.

(b) Arjun (*Terminalia arjuna*)

Family- Combretaceae

Gall causing agent – *Tamarixia sheebae, Narendran spp.* (Hymenoptera, Chalcidoidea)

The average gall/leaf varies from 0.62- 5.8 cm for *Terminalia arjuna.* It is evident from the data that the rainy season (July-August) is the period for the peak infestation. This is evident from gall percent as well as mean number of galls/leaves [21].

2. Gall infestation in Temperate Tasar silkworm host plant

(a) Oak (*Quercus inaca*)

Family- Fagaceae

Gall causing agent – *Zapatella pujade* (Hymenoptera, Cynipidae)

Galls on oaks are most often caused by small wasps or midges. Insects that cause galls to form are known as gall-makers. Galls grow to surround the tiny insects that form them and provide them with protection from weather, predators and parasitoids. The insect develops and grows inside the gall during the summer and emerges as an adult either in the summer or the following spring.

3. Gall infestation in muga silkworm host plants

(a) Som (*Persea bombycina*)

Family- Lauraceae

Gall causing agent- *Asphondylia spp.* (Diptera, Cecidomyiidae)

Asphondylia spp. was recorded as a gall fly. The maggot of this insect is very minute and white in colour. The full fed maggot is 1.5 mm in length. Its body is covered by white hairs. The pupae and adult are black in colour. The larval stage lasts from two weeks to more than two years. Feeding damage is caused by the larvae, which suck plant juices inside galls. Some larvae pupate within their galls, while others exit the galls and pupate in the soil. Most of the gall midges are host specific. The galls may be spherical or resemble thorns. Sometimes, the gall infestation occurs in the tender leaves. The population density of galls in Some plant can be observed maximum during April- May and minimum during October-November [22].

(b) Soalu (*Litsea polyantha*)

Family- Lauraceae

Gall causing agent- *Pauropsylla beesoni* (Homoptera, Psyllidae)

The insect is a minute one with transparent abdomen with transverse light black stripes. The average size of the adult is about 2mm in length and 2.5mm in wing expanse. The gall formation is seen on both the side of the leaf, but most of the galls formed on the upper side. The galls were round or oval

in shape. Gall insects occurred on Soalu plants throughout the year. During March, April and May, 100% plants infestation is recorded. A minimum of 50% plant infestation is recorded during November. The percentage of infestation is recorded during February to May. The infestation is also higher during August- October [23].

(c) Dighloti (*Litsea salicifolia*)
Family- Lauraceae
Gall causing agent – Not been identified yet.
It has been reported that there is a gall infestation in the dighloti leaves and numerous warts are formed on both the sides of the leaf formed by the wasps. The wart is due to the production of toxic substances emitted by the wasp. The galls are globose in shape, while dissecting those gall it has been found that galls contain larva which are whitish translucent in colour whereas the gall is greenish in colour [24].

(Galls on som plant)

(Galls on soalu plant)

(Galls on dighloti plant)

Conclusion
This review emphasizes on the major species that cause galls, types of galls, gall diversity, mechanism of gall formation including the adaptive significance**.** Study of gall diversity along with its causal agents have implications on different gall forming agents on broad flora diversity of the world. The present study also focuses on the adaptive significance of different galls formed on the plants thereby, distinguishing their ability to adapt to wide range of environment. Furthermore, the study of gall infestation on different sericultural host plant could enable various researchers to get information regarding various gall forming insects on the host plants of the silkworms. Thus, changes in biochemical constituents, nutritional (macro and micro elements) and photosynthetic pigments due to gall infestation leads to inferior quality of leaves. The impact of feeding such inferior quality leaves to the silkworm larvae and found a hindrance in their good growth and development, which ultimately results in low quality and poor yield of natural silk fiber. Studies can be further extended to impact of feeding on the poor quality of leaves on the life cycle, biology and development of silk worms.

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