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Review article

Impact of *Cornegenapsylla sinica* Gall Formation on The Distribution of Longan (*Dimocarpus longan*) Photosynthetic Products

Nida An Khafiyya, Nurfajri Eka Fitri and Mukhamad Su'udi*

Biology Department, Faculty of Mathematics and Natural Sciences, Jember University, Kalimantan 37 St., Tegal Boto Jember, 68121, Indonesia.

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*Coresponding Author :
msuudi52@gmail.com

Abstract

Cornegenapsylla sinica is an insect from the Psylloidea family that is capable for inducing the formation of galls on *Dimocarpus longan* plant leaves. The galls formed in the form of a protrusion on the adaxial side of the leaf, due to the depression on the abaxial side, the result of a puncture by the nymph of *C. sinica*. The formation of galls on the leaves of *D. longan* causes changes in the morphological, anatomical, and physiological structures of *D. longan*. Changes in the morphological structure, anatomy, and physiology of leaves which play an important role in photosynthesis and its distribution, will disrupt the process of photosynthesis and the distribution of assimilates. In addition, increased oxidative stress, decreased number of stomata, and decreased CO_2 assimilation occurred in plant organs with galls.

INTRODUCTION

Herbivory is the activity of herbivores eating plants (Mostafa *et al*., 2022; War *et al*.,2018; Kerchev *et al*., 2012). Insects are herbivores that are grouped into two groups based on how they eat (Wari *et al*., 2021; Davidson-Lowe *et al*., 2019). First, a group of insects that eat plant parts directly (chewing insects). Second, a group of insects that suck nutrients from plant tissue (piercing and sucking insects) (Raupp *et al*., 2020; Waterman *et al.*, 2019; Davidson- Lowe *et al*., 2019). The sucking insect group has a large number and many become pests that threaten agricultural production (Wari *et al*., 2021).

The sucking insect has a characteristic form of a sucking-piercing type mouth apparatus. One group of insects with the type of piercing-sucking mouthparts is Hemiptera. Order Hemiptera, consisting of aphids (*Aphidoidea*), psyllids (*Psyllidae*), scale insects (*Coccidae*), mealy bugs (*Pseudococcidae*), and many more (Wari *et al.,* 2021). Psyllids or fleas are insects that have the behavior of eating to suck up nutrients in the phloem tissue of plants. This behavior is generally carried out by psyllid nymphs on specific hosts and causes the formation of galls (Burckhardt and De Queiroz, 2012).

Gall is a neoform structure in plants that are formed due to specific induction by inducers such as insects. This structure is formed due to the plant providing a self-defense response by forming a physical barrier on its plasma membrane. The structure of gall formation is generally specific to the inducing species and the host plant. Apart from its structure, its anatomy and metabolism are also specific. This structure can cause changes in the morphology, anatomy, and physiology of the host plant (Ferreira *et al*., 2019; De Oliveira *et al*., 2010).

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Cornegenapsylla sinica synonymous with *Neophacopteron euphoria* and *Phacopteron sinicum* is a species of the Psyllidae family which is distributed in Southeast Asia. This species commonly attacks *Dimocarpus longan* (*Sapindaceae*) as a host plant (Percy *et al*., 2016). Adult insects lay their eggs in the veins under the leaf surface (Tran *et al*., 2019). *Cornegenapsylla sinica*, which is immature (nymph phase), induces the formation of a gall in the form of a protrusion on the adaxial side of young *D. longan* leaves (Figure 1). The space formed by the protrusion on the adaxial side of the leaf is used as a shelter for *C. sinica* nymphs from the first instar. Therefore, a systematic review was carried out regarding the impact of the attack by *C. sinica* (gall forming Psyllid) on the transport of nutrients produced by photosynthesis in host plants. (Ferreira *et al*.,2019; De Oliveira *et al*., 2010).

RESULTS AND DISCUSSION

As with animals, plant growth is influenced by abiotic and biotic factors. Plants can deal with abiotic and biotic pressures that exist in their environment to survive. Abiotic pressure for plants can be in the form of drought stress or high salinity, while biotic pressure for plants is in the form of attack by other organisms. These other organisms attack in the form of microbes or insects (Marcec *et al*., 2019).

Insects attacking *Dimocarpus longan* plants formed gall structures (Figure 1). Insect-induced gall forms have distinctive and specific characters between the host and the inducing organism (Table 1.) (Buerki *et al*., 2009). The gall formed on the leaves of *D. longan* due to the induction of *C. sinica* is a type of histioid gall which changes the histological structure of the tissue. The morphological type of gall formed is conical. Gall with a conical shape grows wider from the base to the distal end, so that the apical part is widened and rounded (Isaias *et al*., 2013).

Mechanism of Plant Response to Herbivory

Plants have physiological mechanisms in response to insect attacks. This physiological response of plants is carried out through a secondary messenger mechanism. This secondary message in the form of cellular chemicals will act as a code to convey information from the outside to the interior of the cell. Secondary messages in plants trigger immune responses, including calcium (Ca^{2+}), reactive oxygen species (ROS), and nitric oxide (NO) (Mostafa *et al*., 2022; Marcec *et al*., 2019; Kerchev *et al*., 2012).

The mechanism of the immune response to signals from outside the plant which is mediated by the second message is analogous to the relationship between key and lock. The lock consists of a specific balance of different signals, such as a signaling network between Ca^{2+}, ROS, or other signaling systems, which must fit into the lock to produce the correct physiological response. The lock itself can change even as the signal forms a lock, suggesting that this key-lock relationship reflects the induced fit model seen in typical interactions between enzymes and substrates. The model describes how all these signals work together in response to different environmental cues to provide an appropriate physiological response. The lock to a certain physiological response does not function with an incorrectly constructed key and vice versa, including a malformed signal or a malformed sensor/decoder involved (eg, by genetic mutation) (Mostafa *et al*., 2022; Marcec *et al*., 2019).

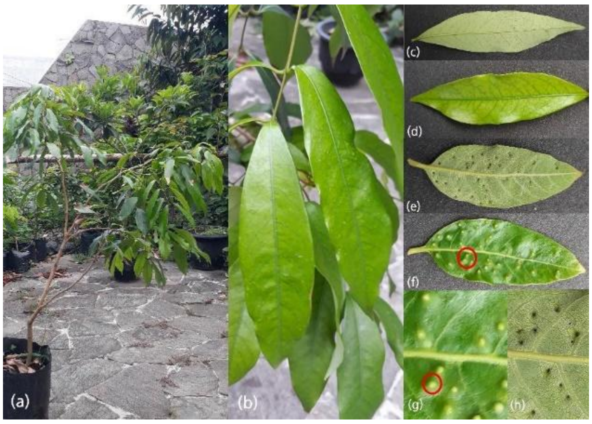

Figure 1. Morphological characteristic of *D. longan.* (a) Longan plant (*D. longan*) habitus; (b) Longan leaves; (c) Abaxial leaves without gall; (d) Adaxial leaves without gall; (e, h) Abaxial leaves with gall; (f, g) Adaxial leaf with gall.

Impact of Gall on Morpho-anatomy

Gall induction caused by insects on *D. longan* forms a protrusion on the adaxial side of the leaf, similar to that of *Pseudophacopteron* sp. on *Aspidosperma australe* (De Oliveira and Isaias, 2010). Mature galls are green to dark green, with rounded projections on both leaf surfaces. This gall has only one inducing insect per nymph chamber. The first instar nymphs of insects induce tissue hyperplasia in all tissues. Compared with leaf tissue without galls, the gall cells are deformed and hypertrophied especially in the host spongy parenchyma. The cells of the abaxial epidermis decrease in size with anticlinal division, increasing the number of ordinary cells and trichomes. This is followed by widening expansion after the formation of the complete nymphal chamber in the adult stage. In contrast, although the area of palisade parenchyma cells increases after induction and gall formation, they have a variable number of layers (one to three).

Table 1. Comparison of several gall-inducing species in the *Sapindaceae* family

Host Species	Gall Inducer Species	Gall Shape	Reference
Blighia unijugata	*Pseudophacopteron fuscivenosum*	Interlaminar	Yana *et al*., 2010
Deinbollia sp.	*Pseudophacopteron electum*	Interlaminar	Yana *et al*., 2010
Lecaniodiscus cupanioides	*Pseudophacopteron lecaniodisci*	Interlaminar	Malenovský *et al*., 2015
Matayba guianensis	*Bystracoccus matayba*	Interlaminar	Barônio and Oliveira, 2019
Litchi chinensis	*Aceria litchii*	Globoid	Carrillo *et al*., 2020
Neoarytera chartacea	*Neocaledonidiplosis neoaryterae*	Globoid	Elsayed and Mille, 2022
Dimocarpus longan	*Dimocarpomyia folicola*	Globoid	Tokuda *et al*., 2008
Serjania sp.	*Cecidomyiidae*	Lenticular, Fusiform, Globoid	Bergamini *et al*., 2017

The vascular bundles and inner parenchyma cells of the galls continue to divide and increase in size as they mature. In addition, the spongy parenchyma changes the cell elongation pattern and expands to form the gall cortex. The mature gall cortex has hypertrophied cells of a cylindrical shape, which take part in gall closure and the consequent formation of the nymphal chamber. Unlike the abaxial side, the adaxial epidermis does not divide (Oliveira, 2020).

Based on the morpho-anatomy of the leaves of Matayba guianensis in the same family as D. longan, namely Sapindaceae, which was induced by *Bystracoccus mataybae* (Eriococcidae) to form galls, with the interlaminar type (Isaias *et al*., 2013), it is known that the density of stomata on the abaxial side of the leaf is higher than the adaxial side of the leaf. In addition, the density of stomata was also lower in leaves that formed galls compared to those without galls. The side of the leaf that forms a gall also has lower total chlorophyll and carotenoids than leaves that do not form a gall. The ratio of chlorophyll and carotenoid content of leaves that do not form galls to those that do form galls is 4:1 or the chlorophyll and carotenoid content of leaves that do not form galls is four times higher than leaves that do form galls (Oliveira *et al*. 2017).

Impact of gall formation on the physiology of longan

Based on research by De Oliveira *et al*. (2010), there was an increase in ROS synthesis during the gall maturation phase. The cytological diagnosis of ROS production and consequent oxidative stress in the galls of *A. australe* plants is the formation of plastoglobules in chloroplasts. According to Rossetti and Bonnatti (2001), the initial event activated by the hypersensitive response (HR) is the production of ROS, including hydrogen peroxide (H_2O_2) and superoxide anion (O_2^-). HR is a mechanism used by plants to fight the growth of pathogens by causing local cell death. A positive reaction to DAB (3,3-diaminobenzidine) indicates the site of ROS production as well as a strong indication of a local response to gall induction. This response also disrupts the membrane system, resulting in cell death in the old phase of the gall. During the aging process, the thylakoid membranes are the first to be degraded, followed by the mitochondrial membranes and the chloroplast sheath.

According to Bailey *et al*. (2015), there is a gene expression response for auxin synthesis in gall tissue. This response is common in all plant gall samples. The regulation of this auxin synthesis gene produced significant differences between leaves with and without galls.

Auxin is produced by plants endogenously as a plant response to environmental stress. This auxin is involved in gall growth. An increase in free auxin was also detected in plant gall tissue. This is possibly caused by the activity of gall-inducing insects. Research by de Queiroz *et al*. (2020), stated that gall-inducing pathogenic organisms are capable of synthesizing auxin, resulting in a hormonal imbalance in plant tissues.

Impact of gall formation on photosynthesis of longan

Based on the physiological and histochemical analysis of galls, the formation of galls disrupts the process of photosynthesis in the host plant. In addition to high oxidative stress, stress is also obtained from insect respiration and insect feeding behavior in the nymphal chamber (the chamber formed by the protrusion of the adaxial side of the leaf). The formation of sinks in the gall and thickening of the parenchyma tissue causes disruption of homeostasis in the body of the host plant. This causes a decrease in CO_2 assimilation and an increase nutrition at the sink in the gall. Decreased CO_2 assimilation causes photochemical activity in tissues to be disrupted or even absent (Oliveira *et al*., 2017; De Oliveira *et al*., 2010).

According to research by De Oliveira *et al*. (2010), on galls induced by *Aspidosperma australe* and *A. spruceanum*, photosynthetic performance as assessed by chlorophyll fluorescence remained unaffected in the presence of galls. Insect galls which do not cause mechanical damage to photosynthetic cells can increase the rate of photosynthesis in their host plants. Despite increased oxidative stress and damage to the chloroplast membrane system, photosynthetic performance was not affected.

CONCLUSION

The impact of the distribution of photosynthetic results on tissues with a gall structure shows the result that photosynthesis occurring in these tissues is disrupted. Disruption of CO_2 assimilation in tissues causes photosynthesis to not even occur at all. This results in damage to the network until death of the network. Research on the impact of the attack by C. sinica on the distribution of photosynthetic products in D. longan needs to be carried out further to obtain more accurate results.

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