

CHAPTER II

LITERATURE REVIEW

2.1 Cassava and its importance

Cassava (Figure 1) is a perennial shrub belonging to the family Euphorbiaceae, which is characterized by the prominent development of lactiferous vessels composed of secretory cells known as laticifers. These cells produce the characteristic milky secretion, or “latex,” that typifies members of this family. Cassava is a monoecious species, bearing both male and female flowers on the same plant, but spatially separated. The leaves are conspicuous and palmately lobed, typically divided into five to nine deep segments.

The storage root of cassava is long and tapered, with a rough, brown periderm. Plant height ranges from 1 to 5 meters, although most cultivars do not exceed 3 meters in height. Morphological variation among cultivars is considerable, ranging from low-growing, highly branched shrubs to slender, unbranched trees.

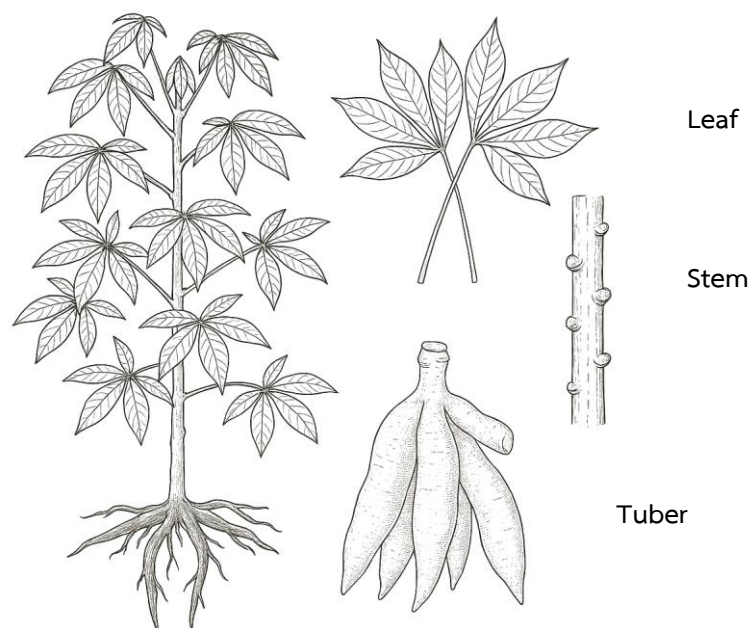


Figure 2.1 The leaves, stem, and tubers of cassava

Source: Adapted from Otálora et al. (2024)

Cassava is recognized as one of the most drought-tolerant crops and can thrive on marginal soils. Under optimal growing conditions, cassava has a yield potential of approximately 90 tons of fresh tubers per hectare and 30 tons of dry matter per hectare (El-Sharkawy, 2004). Although cassava is native to South America, it is now widely cultivated as an annual crop in tropical and subtropical regions. Its starchy, tuberous root constitutes a major source of carbohydrates and plays a critical role in food security. Cassava serves as the basis for a wide range of products (Figure 2).

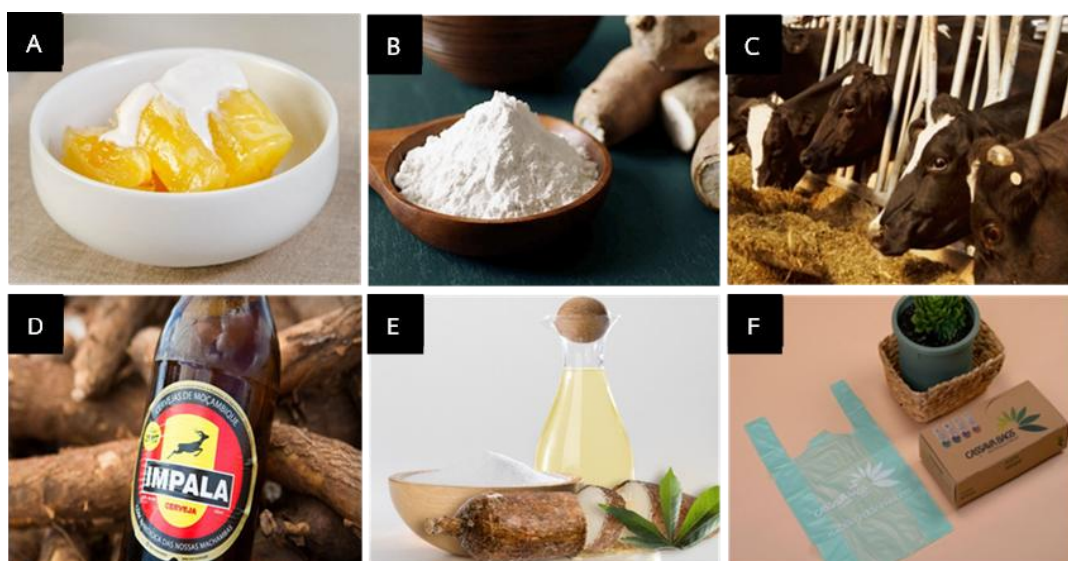


Figure 2.2 Cassava products, including direct consumption as food (A), processed flour (B), animal feed (C), alcohol (D), sweeteners (E), and biodegradable materials (F). Source: Kubala and Lang, (2022)

Thailand is a major global producer and exporter of cassava products, consistently ranking among the top exporters by volume and generating substantial economic value. In 2023-2024, Thai cassava exports alone totaled approximately 150 billion baht. Cassava is not only a crucial economic crop for millions of Thai farmers but also a primary raw material for a diverse range of downstream industries. These include processed food, beverages, pharmaceuticals, cosmetics, chemicals, and ethanol, and are also a key ingredient in the biofuel and animal feed sectors. The adaptability of the Thai cassava industry, particularly its numerous processing factories, enables it to produce a wide range of products and to respond effectively to shifts in global market demand. (Food and Agriculture Organization of the United Nations, 2024).

Thailand has a total cassava plantation area of 10 million rai, with the province with the most planted area being Nakhon Ratchasima Province with a planting area of 1,676,987 rai, followed by Chaiphum Province with a planting area of 894,588 rai and Kamphaeng Phet Province with a planting area of 792,322 rai (Office of Agricultural Economics, 2022).

The cassava varieties used in this study include Huai Bong 60, CMR 89, Kasetsart 50, Rayong 72, Rayong 4, and Pirun 2, which are among the most widely cultivated commercial varieties in Thailand due to their high starch content and adaptability to different agro-ecological zones.

Huai Bong 60, a hybrid of Kasetsart 50 and Rayong 5, resembles Kasetsart 50 in appearance but has lighter purple shoots, more frequent branching, and first branching at 90–140 cm. Its low soluble sugar content enhances starch accumulation, making it highly suitable for industrial processing.

CMR 89, developed under the Kasetsart University and International Center for Tropical Agriculture (CIAT) breeding program, yields approximately 15 t/rai of fresh roots with 22.5% starch. It is characterized by green shoots, silver-green stems, and two levels of branching, making it a high-yielding variety.

Kasetsart 50, a cross between Rayong 1 and Rayong 90, is one of the most widely cultivated varieties in Thailand due to its high adaptability, good germination, and ease of harvesting. It produces ~23.3% starch and ~3.67 t/rai of fresh roots, with purple young shoots, sparse trichomes, and 0–3 branching levels.

Rayong 72, obtained from Rayong 1 × Rayong 5, contains ~21% starch and ~5.5 t/rai of fresh roots. Its drought tolerance makes it particularly suitable for cultivation in the Northeast, and it is identified by dark purple shoots, red petioles, and 0–1 branching levels.

Rayong 4, an early-released breeding line, has moderate starch content (~20–21%) and is commonly used as a reference in breeding trials due to its stable yield performance. Morphologically, it has green shoots, red petioles, and 1–2 levels of branching.

Pirun 2, a hybrid between HB60 and Hanatee, is a newly developed high-yielding variety with ~24.7% starch and ~5.8 t/rai of fresh roots. It is a fast-growing plant with upright, light-brown stems, light-green shoots, and no branches. It grows best in red clay

soils, making it suitable for specific agro-ecological zones (Department of Agricultural Extension, 2017).

2.2 Cassava mosaic disease

CMD is one of the most critical constraints affecting cassava yield. CMD is caused by cassava mosaic viruses belonging to the family *Geminiviridae* and the genus *Begomovirus*. The disease was first reported in the Usambara Mountains of north-eastern Tanzania in 1894 (Warburg, 1894), and it was suggested to be of viral origin in the early twentieth century. The first confirmed outbreak of CMD in Southeast Asia occurred in Cambodia in 2015, followed by subsequent reports from Vietnam, Laos, Thailand, and southern China (Legg et al., 2015; Wang et al., 2019; Uke et al., 2021). Among the virus species identified in CMD-infected cassava from this region, SLCMV is the predominant species. SLCMV is genetically distinct from ACMV and ICMV, yet it induces similar symptoms, including leaf mosaic patterns, leaf distortion, and stunted growth (Wang et al., 2019; Hareesh et al., 2023).

In Thailand, the first CMD outbreaks were reported in the eastern provinces of Prachinburi and Sa Kaeo, later spreading to Buriram, Sisaket, and Surin between 2018 and 2019. Field surveys in affected areas recorded CMD incidence rates of up to 80% in Prachinburi and 43% in Sa Kaeo (Saokham et al., 2021). The primary mode of pathogen transmission is through virus-infected cassava cuttings, with *B. tabaci* serving as a vector (Calatayud et al., 1994). Typical CMD symptoms include leaf lamina distortion, chlorotic mosaic patterns, mottling, and reduced plant size (Figure 10) (Chikoti, 2011).



Figure 2.3 Cassava mosaic disease reduces overall plant size and causes chlorotic

mosaic symptoms.

2.3 Insect vector of cassava mosaic disease

B. tabaci (Gennadius) (Hemiptera: Aleyrodidae) is a major insect vector of CMD (Legg et al., 2011). Among whiteflies, *B. tabaci* and *Trialeurodes vaporariorum* (*T. vaporariorum*) are considered the most economically important species (Agrios, 2008). Both species are pests of crops in open fields and greenhouses. *T. vaporariorum*, commonly known as the glasshouse or greenhouse whitefly, has long been a concern in protected cultivation, whereas *B. tabaci*, originally referred to as the tobacco whitefly due to its prevalence on open-field tobacco, has become a major pest in a variety of field crops, including tomatoes.

Patel et al. (2022) examined the morphology and developmental biology of these two whitefly species. The total developmental duration from egg to adult did not differ significantly between *B. tabaci* (Asia II 5) and *T. vaporariorum*. However, *T. vaporariorum* exhibited greater adult longevity, higher fecundity, and higher adult emergence rates than *B. tabaci* (Asia II 5). Similarly, egg hatching success and immature survival rates were higher in *T. vaporariorum* than in *B. tabaci* (Asia II 5). Morphologically, immature stages of *T. vaporariorum* were larger than those of *B. tabaci* (Asia II 5). Adult males and females of both species could be distinguished by size, wing posture, eye morphology, and antennae, with *T. vaporariorum* being generally larger. Notably, the wings of *T. vaporariorum* rest flat in a triangular shape, whereas those of *B. tabaci* (Asia II 5) are held at an acute angle in a linear fashion, confirming previous descriptions by Ribak et al. (2016). Globally, over 1,500 whitefly species have been recorded, with *B. tabaci* ranking among the most economically significant agricultural pests. *B. tabaci* was first described by Gennadius (1889) as *Aleurodes tabaci*, a tobacco pest in Greece. The genus *Bemisia* was later established by Takahashi (1936), who reclassified *A. tabaci* as *B. tabaci*.

2.3.1 Biology of whitefly *B. tabaci*

Whiteflies are plant feeders with sucking mouthparts. Additionally, adults of both sexes have four membranous wings. Finally, members of the family undergo incomplete metamorphosis. The lifecycle of whiteflies is composed of 6 stages: eggs,

four stages of nymph, and adults. The life cycle is about 42-45 days, eggs 7-10 days, nymphs 17-20 days, and adults 14-16 days (Figure 4). The female lays eggs (approximately 119 eggs/female) singly on the undersurface of leaves. The egg is 2 mm long, pear-shaped, and light yellowish, upright on leaves. The first stage of the nymph is flattened and translucent. The second stage of nymph is expanded and opaque-white with dorsal and lateral waxy, spinelike processes. The third stage of a nymph, when the pharate adult form is present, has red eyes and a yellow body. The last stage is characterized by yellowing and hair around the body. Whiteflies are distinctive in all life stages, except the egg, and can produce extra cuticular waxes that cover the body (Perring et al., 2018).

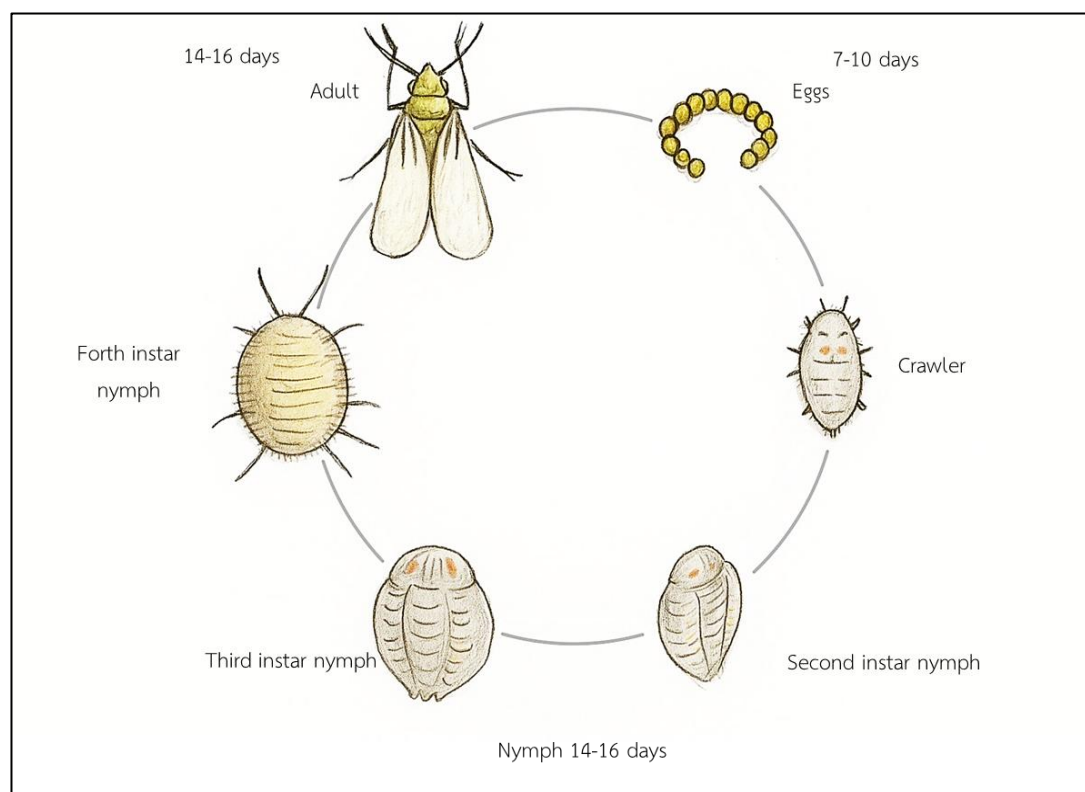


Figure 2.4 Life cycle of the whitefly *B. tabaci*. Source: Syngenta Ornamentals United Kingdom, (2020)

2.3.2 Damage by whitefly *B. tabaci*

Whiteflies damage plants in two primary ways: by directly sucking plant sap and by indirectly excreting honeydew on plant surfaces. Direct damage is inflicted by both adults and nymphs, which insert their piercing–sucking mouthparts, particularly into young plants, to extract phloem sap from sieve tubes (Gangwar and Charu, 2018). This nutrient depletion reduces photosynthetic capacity, leading to leaf yellowing, premature defoliation, plant weakening, and, in severe cases, the death of young plants. Indirect damage results from honeydew secreted by *B. tabaci*, which facilitates the growth of sooty molds on leaves and fruits. These molds inhibit photosynthetic activity and can adversely affect the quality and marketability of agricultural produce (Kunjwal and Srivastava, 2018).

Indirect damage also arises from whiteflies' remarkable role as vectors of numerous plant viruses. To date, *B. tabaci* has been reported to transmit over 200 plant virus species (Lu et al., 2019). The majority belong to the genus *Begomovirus* (family *Geminiviridae*), though whiteflies also transmit *Criniviruses*, *Ipomoviruses*, *Torradoviruses*, and *Carlaviruses* (Navas-Castillo et al., 2011). Crops highly susceptible to these viruses include cassava, cucumber, cotton, cowpea, crucifers, eggplant, tobacco, tomato, potato, soybean, sweet potato, okra, lettuce, pea, bean, pepper, poinsettia, and chrysanthemum (Jones, 2003). Several major viral diseases are transmitted by whiteflies. Cucurbit chlorotic yellows disease (CCYD), caused by the cucurbit chlorotic yellows virus (CCYV, genus *Crinivirus*), infects a broad range of cucurbits, including melon, cucumber, watermelon, loofah, and pumpkin. Typical symptoms include chlorotic leaf spots and progressive leaf yellowing (Okuda et al., 2010). In cotton, cotton leaf curl disease—caused by cotton leaf curl Multan virus (*CLCuMuV*, genus *Begomovirus*)—remains a serious constraint on production. Infected plants exhibit leaf margin curling (upward or downward), vein thickening, and enations (Tang et al., 2015; Pan et al., 2018).

Tomato yellow leaf curl disease (TYLCD), caused by tomato yellow leaf curl Sardinia virus (*TYLCSV*, genus *Begomovirus*), is one of the most devastating viral diseases of tomato worldwide, in tropical and temperate regions. Infected plants show marginal chlorosis, upward curling or cupping of leaf margins, reduced apical leaf size, chlorosis of older leaves, shortened internodes, stunted growth, bushy appearance, and floral abortion, often resulting in severe yield losses (Navas-Castillo et al., 2011).

In mung beans, mung bean yellow mosaic disease (MYMD) is caused by mung bean yellow mosaic virus (MYMV) and mung bean yellow mosaic India virus (MYMIV) (both genus *Begomovirus*), which are transmitted by *B. tabaci*. MYMV is prevalent in Thailand, Pakistan, and western and southern India, while MYMIV occurs in northern, eastern, and central India, as well as in Pakistan, Nepal, and Bangladesh. Symptoms begin with scattered yellow spots on young leaves, which expand into a yellow mosaic pattern, eventually causing complete yellowing, drying, and withering. Infected plants also produce smaller pods, and reduced photosynthetic efficiency leads to significant yield losses (Malathi and John, 2009).

2.4 Transmission of Plant Viruses by Insect Vectors

Many major plant viruses responsible for crop diseases rely on biotic vectors for their transmission. Among these, insects represent the largest group of plant virus vectors. The best-characterized insect vectors include aphids, thrips, leafhoppers, planthoppers, and whiteflies (Bragard et al., 2013). Most insect vectors are sap-feeding species that possess piercing–sucking or chewing mouthparts, enabling them to acquire viruses while feeding on infected plants and subsequently transmit them to healthy plants through the same feeding activity (Agrios, 2008). Transmission by insect vectors generally follows a sequential process (Figure 5).

2.4.1 Acquisition Access Period (AAP)

The AAP refers to the time between the insect's feeding on an infected plant and the pathogen's successful entry into its body. The AAP may last only a few minutes, but it is typically measured in hours. In general, a longer AAP increases the likelihood of pathogen acquisition (Figure 5). Shakeel et al. (2018) demonstrated that a single whitefly *B. tabaci* was sufficient to transmit Cucurbit chlorotic yellows virus (CCYV) to healthy seedlings, requiring approximately 90 minutes of acquisition and inoculation feeding to achieve successful transmission. Similarly, in tomato crops, *B. tabaci* was reported to transmit ToYVSV with a minimum acquisition and inoculation period of 30 minutes (Firmino et al., 2009).

2.4.2 Latent Period (LP)

Following the AAP, the LP is defined as the interval between initial pathogen acquisition and the vector's ability to transmit it. This period, sometimes referred to as the incubation phase (Figure 5), may involve viral replication within the insect and systemic invasion of vector tissues prior to successful transmission. However, not all insect-virus interactions exhibit a latent period. For instance, Shakeel et al. (2018) reported that *B. tabaci* retained CCYV for up to six days post-acquisition.

2.4.3 Inoculation Access Period (IAP)

The IAP occurs after the AAP and LP. It represents the time during which insect vectors transfer viruses from their bodies to uninfected plants (Figure 5). Shakeel et al. (2018) found that a single *B. tabaci* individual could transmit CCYV to healthy seedlings, requiring at least 90 minutes of feeding for successful inoculation. Likewise, *B. tabaci* was reported to transmit ToYVSV in tomato crops with a minimum AAP and IAP of 30 minutes (Firmino et al., 2009).

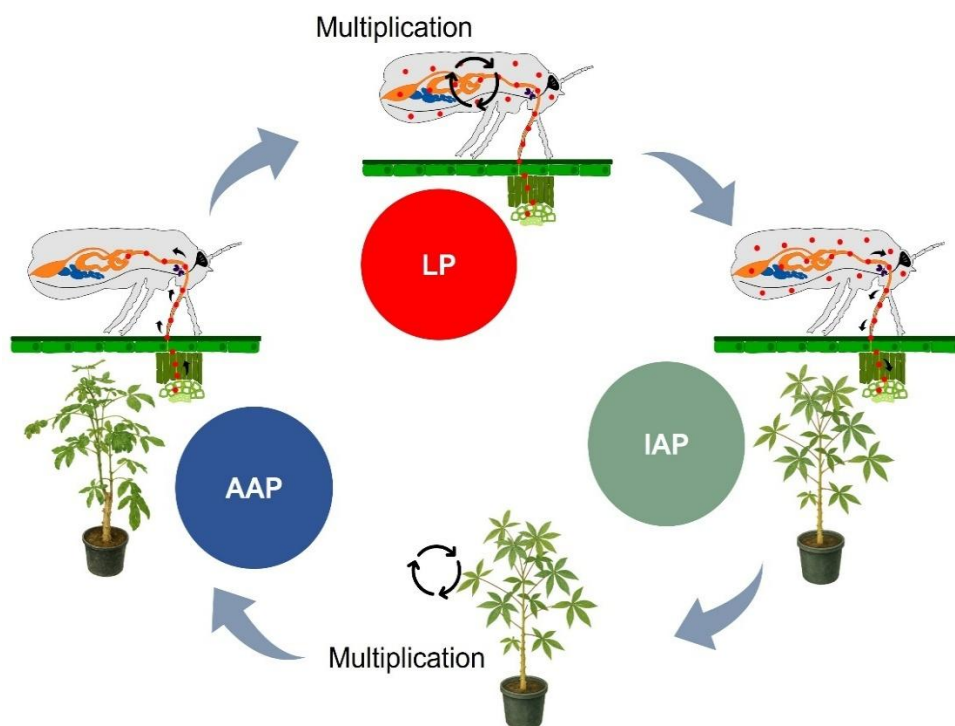


Figure 2.5 The sequential process of transmission of insect vectors

Table 2.1 The time of acquisition access period (AAP), latent period (LP), and inoculation access period (IAP) of whitefly *B. tabaci* vector in plant virus.

Plant virus transmission by whitefly <i>B. tabaci</i>	Transmission process period (hours)			References
	AAP	LP	IAP	
Squash leaf curl virus (SLCV)	-	24	-	Cohen et al., 1983
Tomato yellow leaf curl virus (TYLCV)	48	-	24	Rubinstein and Czosnek, 1997
Pumpkin yellow vein mosaic virus (PYVMY)	0.5	6	0.1	Muniyappa et al., 2003
Tomato leaf curl virus (ToLCV)	0.5	-	0.15	Maruthi et al., 2005
Indian cassava mosaic virus (ICMV)	48	-	48	Antony et al., 2006
African cassava mosaic virus (ACMV)	3	3	0.1	Dubern, J.,1994.
Tomato yellow vein streak virus (TYVSV)	24	16	24	Firmino et al., 2009
Tomato leaf curl bangalore virus (ToLCBV)	0.08	4	0.08	Chowda-Raddy et al., 2012
Tomato yellow leaf curl virus (TYLCV)	72	-	-	Moreno-Delafuente et al., 2013
Sri Lankan cassava mosaic virus (SLCMV)	48	-	48	Duraisamy et al. 2013
Sri Lankan cassava mosaic virus (SLCMV)	24	-	48	Kumar et al., 2014
Cassava brown streak virus (CBSV)	0.05-0.1	48	0.05-0.1	Maruthi et al., 2017
Cucurbit chlorotic yellows virus (CCYV)	1.5	-	1.5	Shakeel et al., 2018

Plant virus transmission by whitefly <i>B. tabaci</i>	Transmission process period (hours)			References
	AAP	LP	IAP	
Tobacco rattle virus (TRV)	48	-	-	Kanakala et al., 2019
Tomato chlorosis virus (ToCV)	48	-	120	Maluta et al., 2020
Pepper vein yellows virus (PeVYV)	48	120	72	Ghosh et al., 2021
Tomato yellow leaf curl virus (TYLCV)	48	-	48	Wendy et al., 2022

2.5 Type of transmission by the insect vector

Once an insect vector acquires a viral pathogen, the manner in which the pathogen is retained, carried, and subsequently transmitted to a new host plant may differ. These differences serve as the basis for classifying insect-mediated plant virus transmission into four main types:

2.5.1 Non-Persistent Transmission: In non-persistent transmission, viruses are retained by the vector only for a few seconds to minutes after acquisition. These viruses cannot be recovered from the insect hemolymph and are not transmissible through injection into the insect hemocoel (Hogenhout et al., 2008). Furthermore, they are lost following molting (Agrios, 2008).

2.5.2 Semi-Persistent Transmission is a form of non-circulative transmission. The viruses cannot be recovered from the insect hemolymph and cannot be transmitted to plants upon injection into the insect vector's hemocoel (Hogenhout et al., 2008). After that, the virus is lost within a few hours after acquisition from the insect body. Consequently, the insect loses the ability to transmit the virus to healthy plants and must feed on another infected plant before it can transmit it again (Webb et al., 2012).

2.5.3 Circulative, Non-Propagative Transmission In circulative, non-propagative transmission, viruses are ingested by the insect vector, traverse the gut wall into the hemolymph, and subsequently reach the salivary glands, from which they are discharged with salivary secretions. These viruses can be experimentally recovered from the hemolymph, remain transmissible after hemocoel injection, and are not lost from the vector once acquired. As a result, vectors may remain infectious for several weeks or even throughout their lifespan (Sylvester, 1980). The LP typically ranges from several hours to days (Table 2). Importantly, circulative non-propagative viruses do not replicate within their vectors and are not transmitted transovarially to the progeny of infected females (Nault, 1997).

2.5.4 Circulative, Propagative Transmission shares many features with the circulative non-propagative type. Viruses in this group also pass from the gut to the hemolymph and then to the salivary glands, where they are secreted during feeding. However, unlike non-propagative viruses, propagative viruses replicate within the insect vector's body (Shikata, 1979; Ammar and Nault, 1985). The latent period may extend

from several days to weeks and can persist across the insect's developmental stages. Additionally, some propagative viruses are transmitted transovarially from infected females to their eggs (Agrios, 2008).

Table 2.2 Transmission characteristics and timing of plant viruses transmitted by insects.

Biological characteristic	Nonpersistent stylet-borne	Semipersistent foregut-borne	Persistent circulative	Persistent propagative
AAP and IAP	Seconds, minutes	Minutes, hours	Hours, days	Hours, days
LP	None	None	Hours, days	Days, weeks
Retention time in vector	Minutes, lost after molting	Hours, lost after molting	Days, weeks	Lifespan of an insect
Presence in the vector's hemolymph	No	No	Yes	Yes
Multiplication in vector	No	No	No	Yes
Transovarial transmission	No	No	No	Often
Insects	Aphid, Whitefly	Aphid, Whitefly	Plant hopper, Whitefly	Leafhopper

Modified from: Hogenhout et al. (2008)

When investigating interactions between plant viruses and other pathogens within insect vectors, direct visualization of the pathogens is essential. Determining their localization and abundance within the vector provides valuable insights into transmission mechanisms. Fluorescence *in situ* hybridization (FISH) is a powerful molecular technique that enables the detection and localization of specific nucleic acid sequences within tissues or whole organisms using fluorescently labeled probes.

This method allows researchers to precisely identify the location of pathogens within vectors, thereby supporting the classification of transmission types.

FISH is primarily applied for the spatial detection and quantification of nucleic acids in their cellular environment (Huber et al., 2018). The technique was originally developed to study specific regions of individual chromosomes within intact cell nuclei. Early applications involved mapping DNA sequences to specific regions of human chromosomes by hybridizing fluorescently labeled DNA probes to complementary chromosomal targets. Under a fluorescence microscope, this produces distinct fluorescent signals at the chromosomal sites of probe binding. The first single-copy human gene mapped using FISH was the thyroglobulin gene in 1985 (Landegent et al., 1985). This cytogenetic approach emerged approximately 30 years after the development of immunofluorescence-based protein detection methods (Chial, 2008).

Modern applications of FISH employ fluorescent probes that hybridize complementary sites in target DNA sequences. The emitted fluorescence provides direct evidence of the location of a specific sequence within the DNA molecule. The fundamental principle of FISH is the hybridization of fluorescent probes with complementary nucleotide sequences (O'Connor, 2008).

Using this approach, Klot et al. (2009) investigated the transmission mode of *Tomato yellow leaf curl virus* (TYLCV; *Begomovirus*, Geminiviridae) transmitted by *B. tabaci*. The virus was localized in the hindgut of *B. tabaci*, while no virus particles were detected in the surrounding eggs. This indicates that TYLCV is not transmitted transovarially. Therefore, the transmission type of TYLCV is classified as circulative, non-propagative (Figure 7).

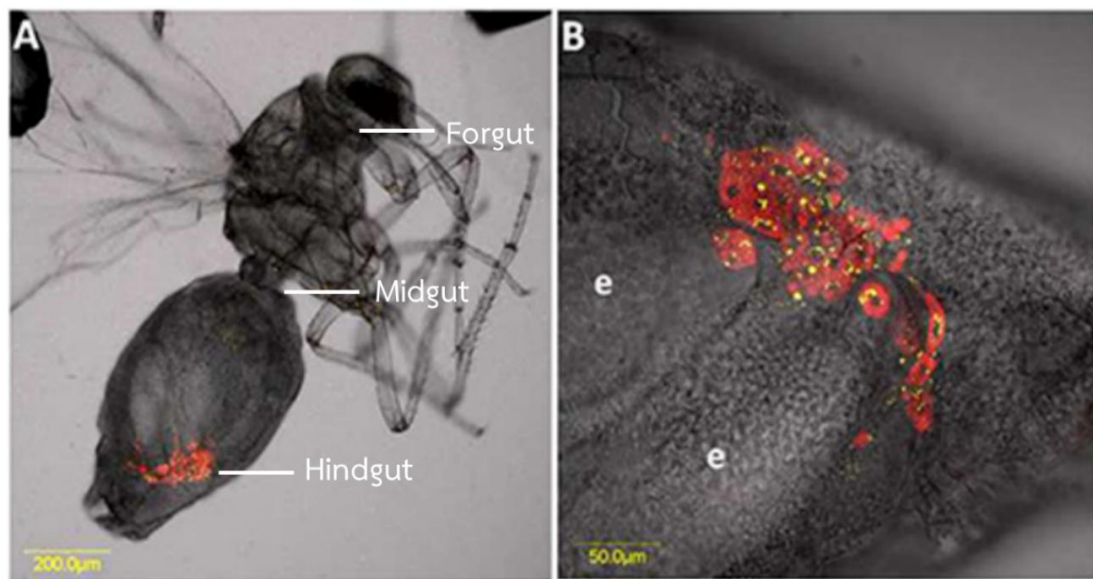


Figure 2.6 Localisation of TYLCV (red) in *B. tabaci* Q biotype adult (A) using FISH technique and zoom on the labeled area (B), e: egg.

Source: Kliot et al., (2009)

Moreover, Roddee et al. (2018a) use FISH to study the transmission type of sugarcane white leaf phytoplasma transmission by the leafhopper *Matsumuratettix hiroglyphicus*. The presence and location of sugarcane white leaf (SCWL) phytoplasma in the adult insects at days 7, 14, 21, and 28 of LP were also determined by FISH. The amount of SCWL phytoplasma increased over time at 7 and 14 days of LP (Figure 8). Therefore, the transmission type of TYLCV is circulative and propagative.

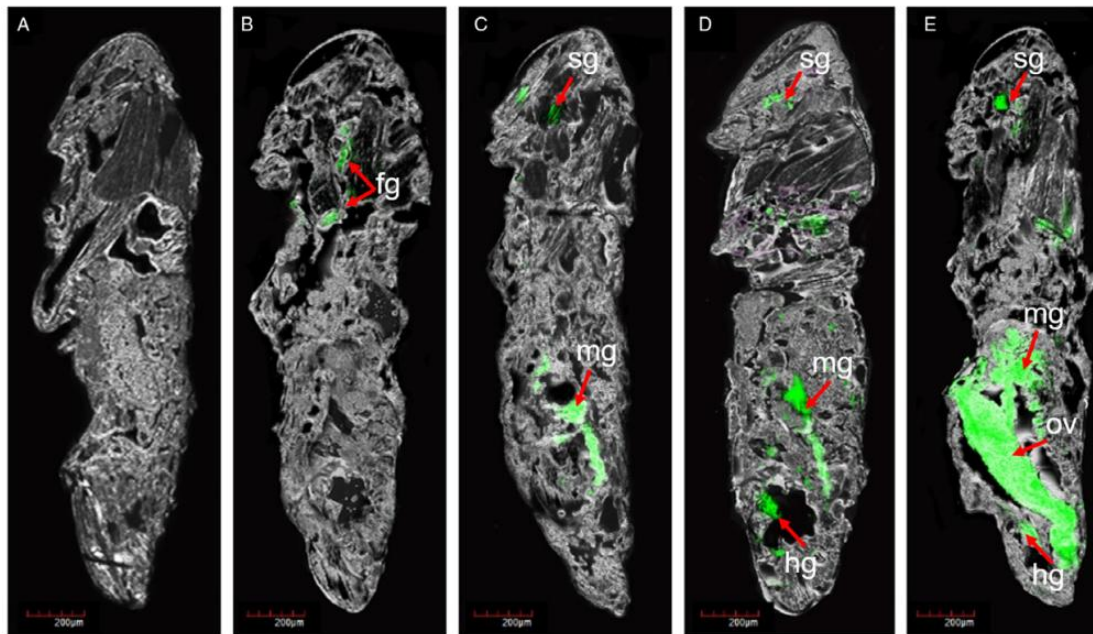


Figure 2.7 Localisation of sugarcane white leaf phytoplasma (green) in longitudinal tissue sections of *M. hiroglyphicus* using the FISH technique. fg, foregut; sg, salivary gland; mg, midgut; hg, hindgut; ov, ovary.

Source: Roddee et al. (2018a)

Kliot and Ghanim (2015) investigated the bacterial symbionts associated with the whitefly *B. tabaci*. Bacteriomes play a crucial role in transmitting symbiotic bacteria from one generation to the next. In some insects, symbiotic bacteria colonize the surface of the digestive system's epithelial cells. Many of these bacteria are obligate intracellular organisms that cannot be isolated or cultured on artificial media, making FISH microscopy an indispensable tool for their detection and for studying their functions, transmission pathways, and tissue tropism. Aphids, whiteflies, and several other insect species possess bacteriomes that harbor both primary, essential endosymbionts and secondary endosymbionts. The application of FISH probes has enabled three-dimensional visualization of these bacteriomes in aphids and across multiple developmental stages of whiteflies, including eggs, larvae, pupae, and adult males and females. With the increasing availability of genomic sequences of various endosymbiotic and pathogenic bacteria, such as spiroplasmas and phytoplasmas, more specific FISH probes have been developed. These probes facilitate the precise detection and identification of distinct bacterial species within insect hosts.

One notable case is the secondary symbiont *Rickettsia* in *B. tabaci*. FISH analysis revealed that *Rickettsia* is distributed throughout the body across different developmental stages, including eggs, nymphs, and adults. This wide localization indicates that the transmission mode of *Rickettsia* in *B. tabaci* is circulative and propagative, involving transovarial transmission from females to their offspring.

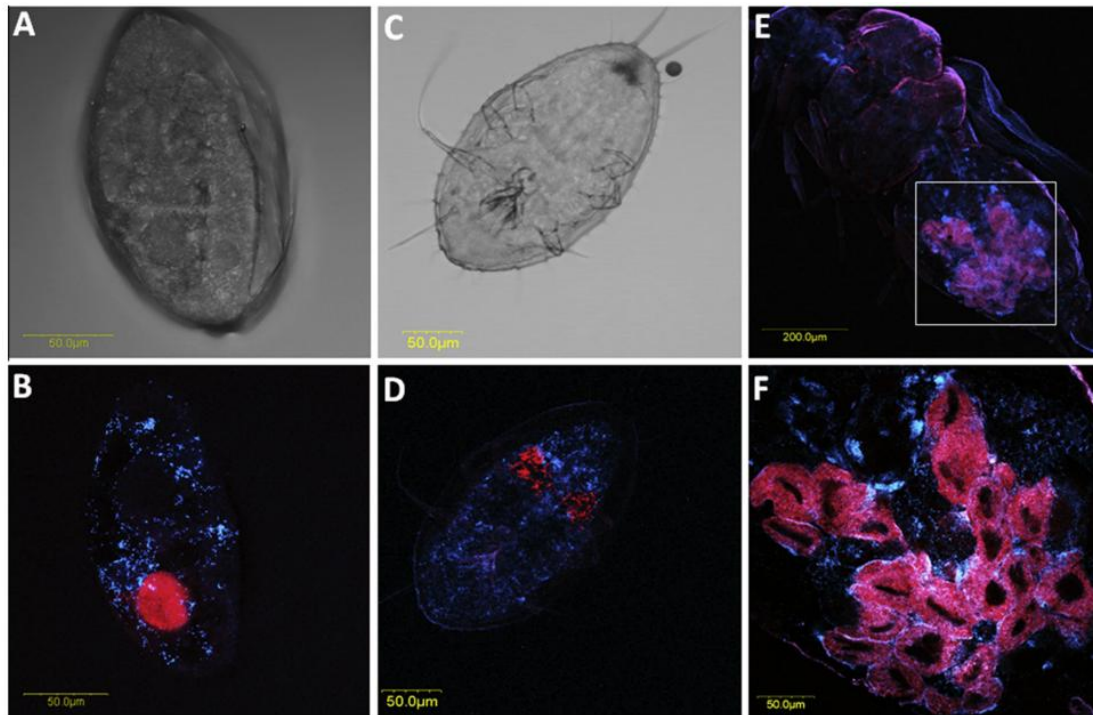


Figure 2.8 FISH on egg, nymph, and adult of *B. tabaci* showing the localization of the primary symbiont *Rickettsia* (blue). Source: Kliot and Ghanim (2015)

2.6 Management Strategies for cassava mosaic disease

A variety of strategies have been implemented to manage CMD. The use of virus-free planting material through clean seed systems helps prevent the introduction of the virus into new fields, although it does not stop secondary spread by vectors (Ntawuruhunga et al., 2017). Chemical control of whiteflies with insecticides has also been widely adopted. However, concerns about environmental safety, cost, and the development of resistance make this strategy less sustainable in the long term (Ghosh et al., 2022). In addition to insecticides, physical trapping methods such as yellow sticky traps have been used as an eco-friendly, low-cost tool for monitoring and partially controlling whitefly populations. These traps exploit the whiteflies' attraction

to yellow wavelengths and can reduce adult density when deployed strategically across the field, especially during early infestation stages (Reddy et al., 2023). While not sufficient as a standalone solution, sticky traps contribute to integrated pest management (IPM) systems by reducing whitefly pressure and helping to delay the spread of viruses. Moreover, breeding programs have focused on developing CMD-resistant cassava varieties using both conventional and molecular approaches. While African breeding programs have made progress, resistance to *SLCMV* in Asian cassava varieties remains limited (Wolfe et al., 2016).

However, resistance to *SLCMV* in Asian cassava cultivars is still under development and not yet widely available. Additionally, host selection is the process by which insect vectors identify, evaluate, and select suitable host plants for feeding and egg laying (oviposition). In the case of *B. tabaci*, host selection is influenced by a combination of visual, olfactory, and tactile cues, including leaf color, shape, surface chemistry, and trichome characteristics. This behavioral preference has significant epidemiological implications: plants that are more attractive to whiteflies are more likely to serve as virus sources, thereby facilitating the rapid spread of disease. Conversely, less preferred plants may act as a form of natural barrier, reducing vector contact and subsequent transmission (Finch and Collier, 2003; Bernays and Chapman, 2007).

2.7 Host plant preference of whitefly *B. tabaci*

The preference for host plants is a fundamental factor influencing the development and survival of herbivorous insects. Host selection, oviposition behavior, and the nutritional demands of offspring are strongly interrelated (Carrasco et al., 2015). Evolutionary perspectives on host plant choice suggest that natural selection favors a close correspondence between female oviposition preferences and offspring performance, commonly referred to as the preference–performance or “mother knows best” hypothesis (Jaenike, 1978). Nevertheless, female choice and larval survival are not determined solely by dietary requirements but are also shaped by additional factors, including predation, parasitism, and both intra- and interspecific competition. Moreover, interactions with pathogenic and beneficial organisms have been shown to significantly influence insect host plant preferences (Mauck et al., 2010). In certain

species, larvae can compensate for maternal choice by leaving the initially selected plant and establishing on alternative hosts (Soler et al., 2012; Gamberale-Stille et al., 2014). Therefore, models of optimal foraging should integrate multiple ecological factors that may cause deviations from a strict association between oviposition preference and host plant quality (Figure 10).

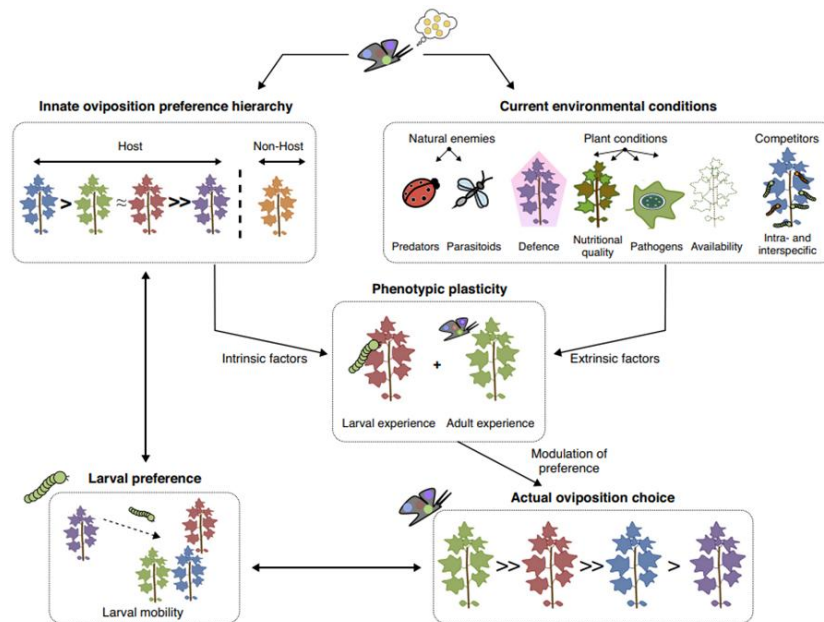


Figure 2.9 Concept of the factors influencing host plant choice in herbivorous insects.

Source: Carrasco et al. (2015)

However, the ultimate host plant suitability is also strongly determined by plant resistance mechanisms, which are broadly classified into tolerance, antibiosis, and antixenosis.

Tolerance refers to a plant's ability to withstand or recover from insect damage without significantly reducing yield or growth (Smith, 2005). While tolerance does not directly affect *B. tabaci* preference, it reduces the pest's overall impact on the crop. Antibiosis involves plant traits that negatively affect insect biology, such as delayed development, reduced survival, or lower fecundity. For *B. tabaci*, antibiosis has been reported in tomato genotypes carrying resistance genes, where nymphal survival is reduced and development is prolonged (Jiang et al., 2001; Firdaus et al., 2012).

Antixenosis, or non-preference, plays the most direct role in host plant selection and preference. Plants exhibiting antixenosis possess traits that deter insect

colonization, oviposition, or feeding. For *B. tabaci*, antixenosis may arise from morphological barriers such as high trichome density, thick cuticles, or epicuticular wax composition (Berlinger, 1986; Toscano et al., 2002). Volatile compounds can also contribute to antixenosis by repelling whiteflies or interfering with host location (Bleeker et al., 2009). For instance, tomato lines with glandular trichomes not only impede settling but also reduce oviposition, demonstrating a strong antixenotic effect (Simmons et al., 2003). In cassava, differences in leaf surface characteristics have been shown to influence whitefly landing rates, further highlighting the role of antixenosis in shaping host preference (Sáinz et al., 2019).

2.8 Reference

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