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PHYTOPHAGOUS MITES OF MULBERRY: AN INVISIBLE THREAT TO SERICULTURE

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ABSTRACT
Sericulture, the principal source of silk, requires high-quality *Morus* spp. (Rosales: Moraceae), leaves for healthy silkworm growth, high cocoon yield, and better silk quality, while contributing to nutritional needs, medical applications, livestock fodder, and environmental sustainability. Although its growth, quality and productivity are severely hindered by many biotic and abiotic factors, insect (defoliators, sap sucking, stem borers and soil pests) and non-insect (phytophagous mite) pests, majorly affect the growth of silkworm, reducing larval and cocoon weight, inferior filament length, and compromised reeling performance, causing economic losses. Among these pests, phytophagous mites cause serious damage that goes unnoticed until severe injury occurs. The mites belonging to Tetranychids, Tarsonemids, and Eriophyids are the most important ones causing damage, where moderate infestations slow down silkworm growth and associated parameters. Additionally, recent advances in molecular tools, including DNA barcoding and genomic approaches, are discussed for their role in accurate species identification and development of resistant mulberry genotypes. However, a better understanding of mite biology and mulberry-mite-silkworm interactions has led to safer management practices, such as cultural, botanical, biological control and selective acaricides. Adoption of integrated and silkworm-safe mite management strategies is essential to protect mulberry leaf quality and ensure sustainable silk production.

KEYWORDS: Biochemical properties, management, mites, mulberry, sericulture, silkworm

1. INTRODUCTION

Morus spp. (Rosales: Moraceae) is a multipurpose perennial crop with great economic, ecological, and social importance, but its primary value lies in sericulture, as it is the sole food plant of the silkworm *Bombyx mori* (Lepidoptera: Bombycidae). The growth, health, and silk-producing ability of silkworms depend entirely on the quality and availability of the feed, making sericulture highly sensitive to any factor that affects mulberry foliage (Memete et al. 2022). In addition to supporting silk production, mulberry is valued as a fruit tree, a nutritious livestock fodder, and a source of bioactive compounds used in the food, medicine, and cosmetic industries (Parida et al. 2020), while contributing to environmental services such as carbon sequestration and growth in marginal soils (Baciu et al. 2023).

Modern mulberry cultivation faces increasing challenges due to intensive monocropping, changing climatic conditions, and the continuous availability of foliage, which favours pest buildup (Sakthivel et al. 2019). More than 300 insect and non-insect pest species have been reported worldwide on mulberry, including defoliators, soil pests, sap-sucking insects, and stem and shoot borers, many of which significantly reduce leaf yield and quality (Sakthivel et al. 2019; Haripriya and Mamatha, 2023). Among them, phytophagous mites have emerged as particularly damaging pests, as their feeding causes serious biochemical and structural changes in leaves, leading to poor silkworm growth, reduced cocoon weight, and inferior silk quality (Ramegowda et al. 2012; Mahadeva, 2018) compared to other mulberry pests. In India, mulberry gardens frequently suffer heavy infestations of sucking insects and mites, posing a major constraint to sustainable sericulture (Hosamani et al. 2020). Understanding mulberry and pest interactions and adopting integrated, silkworm-safe management strategies are therefore essential to protect leaf quality and maintain stable silk production.

Previous research on mulberry mite pests has largely examined individual components of the problem rather than a comprehensive framework. Narayanaswamy et al. (1996) reported the diversity, taxonomy, and distribution of mites on mulberry but did not explore their interactions with mulberry physiology or silkworm productivity. (Chauhan et al. 2002) focused mainly on the occurrence and damage symptoms of *Polyphagotarsonemus latus*, emphasising its pest status without comparing other mite species. Studies by (Dar et al. 2011) and Ramegowda et al. (2012) quantified the biochemical and physiological effects of mite infestation on mulberry leaves and silkworm performance, yet they were limited to experimental observations. Likewise, (Sharath et al. 2022, 2024) described mite biology and certain management approaches but did not present an integrated sericulture-based perspective. Thus, the present review synthesises information on species diversity, life-cycle biology, seasonal ecology, biochemical impacts on mulberry leaves, and the effects on *Bombyx mori*, compiling Integrated Mite Management (IMM) strategies such as cultural, botanical, biological, and selective chemical approaches that are compatible with sericulture systems.

This structured literature review therefore provides a consolidated resource for entomologists, sericulture researchers, and policymakers by integrating fragmented knowledge on mulberry–mite–silkworm interactions and highlighting sustainable management options.

The present review was prepared based on peer-reviewed English-language literature published between 1990 and 2025 collected from major scientific databases including Web of Science, Scopus, and CAB Abstracts. Literature searches were conducted using combinations of keywords such as mulberry Pytophagous Mites Tetranychidae,Tarsonemidae and Eriophyidae mulberry pests,sericulture,silkworm and mite management using Boolean operators to refine results. Additional relevant studies were retrieved from Google Scholar and institutional repositories. The collected articles were screened based on title, abstract and full text following the systematic review approach recommended in the PRISMA guidelines (Moher et al. 2009) to ensure relevance and quality of the included literature.

2.1. Significance of Mulberry cultivation

Mulberry is a perennial and deciduous tree known for its rapid growth and wide adaptability across tropical and temperate climates, comprising over 68 species, one subspecies and approximately 500 varieties, with primary centres of diversity in East and South Asia (Memete et al. 2022). In India, *M. alba, M. indica, M. nigra, M. rubra,* and *M. laevigata* are commonly grown, and *M. indica* grows especially well in the warm, dry regions of southern India. Karnataka is the largest mulberry producing state in India, followed by Andhra Pradesh, Manipur, and West Bengal (Parida et al. 2020).

Mulberry thrives under diverse edapho-climatic conditions, growing optimally at 26 °C with 70- 90% relative humidity, annual rainfall of 600- 2500 mm and day lengths of 9-13 hours, and can be cultivated from lowlands up to 4000 meters above sea level (Jan et al. 2021). The crop prefers fertile, well drained loamy to clayey soils with neutral pH (6.2–6.8), and imbalances in nutrients such as sodium, potassium and phosphorus predispose plants to pest and disease attack (Vijayan, 2010).

2.2. Phytochemical and nutritional attributes

Mulberry leaves and fruits are rich in polyphenols, including rutin, quercetin, gallic acid and chlorogenic acid together with DNJ (1-deoxynojirimycin), anthocyanins and polysaccharides (Ma et al. 2019) that confer antioxidative, antidiabetic, anti-inflammatory, hypolipidemic and neuroprotective properties (Zhang et al. 2019). Red and black mulberry cultivars may reach total phenolic contents of approximately 481 mg GAE/100 g fresh weight and anthocyanin levels approaching 289 mg/100 g, values comparable to or exceeding those of other berries (Parida et al. 2020).

For *B. mori*, mulberry leaves provide the full complement of proteins, carbohydrates, minerals and vitamins necessary for growth and silk biosynthesis, and classical nutritional ecology studies show that leaf quality accounts for 38% of cocoon productivity (Ruth et al. 2019). Experimental work has demonstrated that improved or vitamin enriched mulberry leaves shorten larval duration, increase fifth-instar larval weight and enhance cocoon and shell traits, effects attributable to higher efficiencies of conversion of ingested and digested food rather than digestibility alone (El-Banna et al. 2013).

2.3. Economic and ecological roles

Besides sericulture, mulberry leaves serve as a high protein fodder (Parida et al. 2020) that improves milk and egg quality while reducing feed costs (Litwińczuk and Jacek, 2020), and the fruits are increasingly used in juices, jams, wines and nutraceutical products (Sarkar et al. 2022). Mulberry plantations also sequester carbon (Baciu et al. 2023), contribute to phytoremediation of heavy metal contaminated soils and provide vegetative cover in degraded and saline landscapes, reinforcing their ecological significance in climate-resilient farming systems (Vijayan et al. 2011).

3. Pests of mulberry and their damage

As a perennial crop bearing succulent foliage, mulberry supports a wide range of more than 300 insect and non-insect pests, though only a subset causes consistent economic damage (Mahadeva, 2018) as listed in Table 1. Major guilds include lepidopteran defoliators, sap-sucking pests, stem and shoot borers, and soil and root feeders (Dhooria, 2016; Sakthivel et al. 2019).

Regional surveys conducted in Ethiopia show that pest composition and dominance vary with environment, but that stem borers, sucking pests and mites persist as key constraints, often acting synergistically with foliar diseases like *Cercospora* leaf spot to depress leaf yield and quality (Tilahun et al. 2014). In India, sucking pests and lepidopteran defoliators were frequently reported as the most damaging groups, particularly in intensively managed gardens.

4. Mite pests of mulberry

4.1. Species diversity

Sixteen species of mites have been recorded on mulberry worldwide as illustrated in Fig 1, including eleven species reported from India, primarily in Tetranychidae (Dar et al. 2012), Eriophyidae (Sharath et al. 2024) and Tarsonemidae (Sharath et al. 2022). Important species of tetranychids include *Tetranychus ludeni*, *T. equatorius* (Narayanaswamy et al. 1996)**,** *T.* urticae (Sharath et al. 2024), and *T. truncatus* (Sharath et al. 2022), the eriophyid *Aceria mori* (Narayanaswamy et al. 1996) and the tarsonemid broad or yellow mite *Polyphagotarsonemus latus* (Sharath et al. 2022), whose combined feeding can affect both bush and tree mulberry systems.

4.2. Symptoms of damage on mulberry

Mites cause fine speckling, bronzing, blistering, leaf curling and deformation of young leaves and buds, symptoms that often mimic nutrient deficiencies (Dar et al. 2011). But these symptoms are accompanied by webbing in spider mites and characteristic distortions in yellow mite infestations (Chauhan et al. 2002)**,** as listed in Table 2 and illustrated in Fig 2.

4.3. Life cycle and developmental biology

Among all the phytophagous mites infesting mulberry, the broad mite *P. latus* is considered to be the most destructive species as they are characterized by extreme phenotypic plasticity, a short life cycle of 4–13 days, comprising of egg, larvae, nymph, adult stages and females lay about 30-76 eggs with female-biased populations (Jeppson et al. 1975; Fasulo, 2004), allowing rapid buildup on young mulberry leaves under favourable temperatures of 25-35°C and moderate to high relative humidity (Gerson, 1992) reported elliptical, translucent eggs, upper surface covered with white tufts, which hatches in 2-3 days and scanning electron microscopy studies show that eggs bear numerous sac-like projections, young larvae possess distinct transverse bands and dense tubercles (Lindquist, 1986), moves slowly with three pairs of legs, white in colour due to ridges, and feeds for 2-3 days, followed by quiescent nymphal stage which appears clear and with pointed ends (Fasulo, 2004) and males exhibit a modified fourth leg and genital capsule used to transport quiescent female nymphs, behaviour that enhances dispersal (Montasser et al. 2011).

T. truncatus completes its development through egg, larva, protonymph, deutonymph and adult stages. Under favourable conditions of 25-30°C and moderate relative humidity, egg-to-adult development takes 8-12 days, allowing rapid population increase during warm seasons. Eggs hatch within 2-3 days, followed by a larval stage of 1-2 days and two nymphal stages, each lasting 2-3 days, separated by brief quiescent periods. Adult females are long lived, contributing disproportionately to population buildup (Sharath et al. 2022). Demographic studies on *P. latus* and *T. truncatus* in mulberry indicate that the yellow mite completes its life cycle in 3-4 days (male) and 4 days (female), whereas *T. truncatus* requires 9-10 days (Sharath et al. 2022), and both species show strongly female-biased sex ratios. These traits, together with phoretic dispersal and broad host range, explain the frequent explosive mite outbreaks in mulberry (Mohan et al. 2024).

The developmental period of *T. urticae* recorded by (Elsadany, 2018)**,** shows that it completed its life cycle in 9-10 days, with a generation time of 11-12 days and 96% egg hatchability. *T. ludeni* showed rapid development on mulberry leaves, having a short developmental period of 8-10 days and high fecundity under temperatures of 25–32°C (Bolland et al. 1998), and morphologically they have elongated dorsal setae and a distinct aedeagal shape (Jeppson et al. 1975)**.** The life cycle consists of an egg, a larva usually six-legged, followed by a protonymph and a deutonymph (the first and second eight-legged stages without genitalia), and finally a mature adult (Sharath et al. 2024), reproducing through a haploid-diploid system. *Aceria mori,* predominantly found in East and South Asia, completes its life cycle within 7-10 days under warm and humid conditions, and scanning electron microscopy (SEM) analysis showed an elongate body with two pairs of anterior legs and feather claw empodia adapted for feeding within leaf tissues (Lindquist, 1986).

4.4. DNA barcoding in mulberry mite identification

Determination of mite species should be accurate for developing effective pest management strategies. Although traditional ways of morphological identification remain fundamental it remains challenging due to the minute size of mites, high phenotypic plasticity and externally look alike complex in mites. Pertaining to these constrains molecular identification particularly DNA barcoding has emerged as powerful and reliable tools in modern acarology. It utilizes standardized genetic markers with commonly employed markers including the mitochondrial cytochrome oxidase I (COI) gene, internal transcribed spacer (ITS) regions and ribosomal RNA genes such as 18S and 28S, all of which provide strong taxonomic reproducibility across diverse mite taxa. To visualise the steps involved in DNA barcoding, literature-based integration is presented in Fig 3.

Recent advances in molecular taxonomy have significantly refined the classification and phylogenetic understanding of economically important mites. Sequence based analyses have clarified interspecific relationships within the genus *Oligonychus* and resolved taxonomic uncertainties among spider mites (Mushtaq et al., 2023). Similarly, integrative approaches combining molecular data with morphological characteristics have enhanced species delimitation and evolutionary insights across multiple mite groups (Dabert et al., 2010; Skoracka et al., 2015). Additional studies have also demonstrated the effectiveness of COI-based barcoding in distinguishing closely related tetranychid species and detecting cryptic diversity (Navajas et al., 1996; Hebert et al., 2003;

Cruickshank, 2002). The integration of molecular diagnostics with conventional taxonomy thus represents a crucial advancement for accurate species identification, enabling more efficient pest surveillance, timely intervention, and sustainable management of mulberry pests.

4.5. Seasonal dynamics and spatial distribution

In mulberry across temperate and subtropical sericultural regions, mite populations show seasonal patterns, rising from low levels in early summer to peaks in mid- to late summer, then declining in autumn (Sharath et al. 2024). In Kashmir, mite incidence on mulberry leaves increased from 25% in June to 62% in late August, then declined to 18% by October, adopting a bell-shaped curve strongly influenced by temperature, relative humidity and antecedent rainfall (Dar et al. 2012).

Spatially, *P. latus* is highly aggregated on young upper-canopy leaves, particularly the third to fifth leaves from the apex (Arunkumar and Srinivasa, 2021), where densities may exceed 100 mites/cm², while older leaves harbour few individuals (Gowda and Jagadish, 2025). *T. turkestani* attained peak densities of 6.5 mites per 25 cm² in July–August (Dar et al. 2017), with variety-specific differences in abundance; variety Ichinose supported the highest populations, while Tr-10 showed relative resistance.

T. truncatus and *P. latus* are spread across the states of Karnataka, Tamil Nadu, Andhra Pradesh, and parts of eastern and northeastern India. The buildup of population emerges soon after pruning, with fresh, tender foliage, reaching a peak during warm, dry seasons, and it declines markedly during the monsoon period. Post-monsoon resurgence is common, underscoring the need for seasonal and location-specific management strategies (Jeppson et al. 1975). Beyond seasonal fluctuations in mulberry ecosystems, phytophagous mites exhibit wide host associations across multiple crops and agro-ecological regions. To illustrate these relationships and the relative prominence of different mite taxa on host plants, a literature-based synthesis is presented in Fig 4.

4.6. Mulberry and herbivore studies

Resistant mulberry genotypes exhibit thicker cuticles, tougher leaves and increased trichome density, alongside elevated levels of secondary metabolites (phenolics, flavonoids, tannins, alkaloids, latex proteins, lectins) that interfere with larval digestion, and herbivory induces defense related enzymes and jasmonic acid and salicylic acid mediated signalling pathways that modulate protease inhibitors (Ahmad et al. 2025).

These defence traits fit within broader theories of plant insect coevolution and nutritional ecology, in which host-plant quality and defence chemistry jointly determine herbivore growth and adaptation (Scriber and Slansky, 1981). While analogous molecular level work on mites is comparatively limited, the observed phenolic accumulation and altered protein and sugar profiles in mite infested leaves suggest similar defence nutrition trade-offs that may influence both mites and silkworms (Dar et al. 2011; Sharath et al. 2024).

4.7. Biochemical and physiological effects on mulberry leaves

Mite feeding alters mulberry leaf biochemistry in ways that reduce its nutritive value for silkworms (Baciu et al. 2023), which includes sharp reductions in crude protein, total sugars, starch and chlorophyll, accompanied by increases in phenolic compounds and leaf toughness. The studies made by (Dar et al. 2011) documented a drop in protein content, from 36.5 mg g^{-1} in healthy leaves to 23.7 mg g^{-1} in infested leaves, total carbohydrates from 98.7 to 73.1 mg g^{-1} and chlorophyll index from 16.25 to 10.13, while phenolics rise, reflecting stress responses. Under severe mite infestation, leaf protein, soluble sugars and starch were reduced by 22–41%, total chlorophyll declined by more than 30%, while leaf toughness increased by about 1.4-fold and phenolic content rose by 35–50% compared with uninfected mulberry leaves (Ramegowda et al. 2012), indicating progressive biochemical deterioration with increasing mite density

These biochemical shifts correspond to visible symptoms such as yellowing, speck coalescence, bronzing, curling, leathery texture and premature leaf fall, consistent with toxin-mediated physiological disruption described in other hosts of *P. latus* (Mahadeva, 2018). The cumulative effect is a leaf that is both nutritionally and structurally altered, with consequences that propagate through to silkworm performance and silk quality.

4.8. Mulberry, pests and silkworm relationship

In sericultural research, feed quality is determined by genotype, agronomy and pests prevailing being the primary driver of silkworm growth and cocoon productivity (El-Banna et al. 2013; Tilahun et al. 2014). Pest and disease damaged mulberry leaves significantly diminish silkworm performance, with reductions reported in larval weight, cocoon weight, shell weight, shell ratio and filament length (Sullia and Padma, 1987).

4.8.1 Nutritional requirements of silkworm

The nutritional physiology of the silkworm, *Bombyx mori*, has been extensively investigated owing to its strict monophagy on mulberry leaves. Proteins represent the most critical dietary component, constituting nearly 60-65% of the larval dry mass during active feeding stages, with fourth instar larvae reported to contain as much as 63.68% protein on a dry matter basis, reflecting growth and silk gland development (Horie, 1978). Mulberry leaves supplying 18–22% crude protein (dry weight) are considered optimal, as inadequate protein intake leads to reduced larval weight, poor cocoon shell ratio, and inferior silk output (Rahmathulla et al. 2004). Carbohydrates form the primary energy source, accounting for nearly 48-50% of the mulberry leaf dry matter, and are efficiently absorbed and metabolized, with studies showing high concentrations of carbohydrates in larval tissues, particularly in the fat body (245 mg g^{-1}) and haemolymph (195 mg mL^{-1}), where they circulate mainly as trehalose and are stored as glycogen (Ito and Tanaka, 1960). Lipids, though required in comparatively smaller quantities during larval stages, accumulate substantially during metamorphosis, with pupae containing 20-35% lipid on a dry matter basis, serving as major energy reserves during non-feeding stages (Horie, 1978).

Vitamins, particularly B-complex vitamins such as thiamine, riboflavin, pyridoxine, pantothenic acid, biotin, and folic acid, are indispensable for enzymatic and metabolic regulation, while choline and inositol are required in relatively larger amounts due to their lipogenic and structural roles rather than catalytic functions (Dadd, 1985). Mineral nutrients derived entirely from mulberry leaves, including potassium, calcium, magnesium, iron, zinc, and manganese, regulate enzyme systems, osmotic balance, and silk gland physiology, and deficiencies or imbalances have been shown to adversely affect cocoon weight and shell ratio (Shankar, 1990). Water, largely supplied through fresh leaves, is equally essential for digestion, nutrient assimilation, and metabolic homeostasis, and variations in leaf moisture content significantly influence feeding efficiency and larval performance (Rahmathulla et al. 2004).

Silkworms reared on nutritionally superior varieties such as Kokuso-27 and Sh2×Lunlog attain higher fifth-instar larval weights, shorter larval periods and higher effective rates of rearing (El-Banna et al. 2013) than those fed on inferior varieties like *M. alba* var. Leavigata, which prolongs development and reduces survival (Sabhat et al. 2011). Silkworms fed on Mahali and Shin Ichinose varieties showed high efficiency of conversion of ingested food (ECI) and digested food (ECD), favouring growth rates and those fed on Kenmochi exhibited high approximate digestibility but low conversion, ultimately resulting in poor biomass gain (Kanafi et al. 2007). Further studies on varieties Ichinose and Kenmochi (Oftadeh et al. 2014) showed that, despite high digestibility, they exhibited low ECI and ECD values, leading to poor biomass gain because ingested nutrients were inefficiently converted.

4.9. Impact on silkworm rearing and reeling parameters

Mite infestation causes leaf degradation as it is often overlooked until biochemical and structural changes are well advanced; infested leaves show declines in moisture, chlorophyll and crude protein, increases in phenolics and toughness and, consequently, reduced palatability and nutritional value for silkworms (Dar et al. 2011; Baciu et al. 2023). These changes translate into measurable reductions in larval growth, cocoon parameters and reeling performance even at moderate infestation levels (Dar et al. 2011; Ramegowda et al. 2012).

Field and laboratory studies have quantified the impact of mite-infested mulberry leaves on *B. mori*, revealing consistent and substantial declines in rearing performance and reeling traits (Gowda and Jagadish, 2025). In Kashmir, larvae fed on mite-infested leaves exhibited extended larval duration by about three days, reduced larval weight by 1.16–1.26 g and increased susceptibility to diseases, with concomitant increases in labour and feed requirements (Dar et al. 2011; Ramegowda et al. 2012).

Cocoon weight declined by 0.5 g, shell weight by 0.114 g, shell ratio by about 4% and filament length by 260 m, while denier decreased by one unit (Ramegowda et al. 2012), and these differences scaled with the severity of leaf damage. Varietal differences were evident by the results of (Dar et al. 2011) in which the varieties KNG and Goshoerami showed comparatively better resilience to mite injury, whereas Ichinose was highly susceptible (Dar et al. 2017), reflecting interactions between leaf nutritional quality and mite-induced deterioration. The effects of mites infesting mulberry plants and their adverse effects on plants and silkworms are depicted in Fig 5.

5. Management of mulberry pests with special reference to mites

5.1. Cultural practices

Cultural practices form the first line of defence against mite outbreaks in mulberry gardens. Regular pruning and removal of infested shoots, timely weeding, balanced fertilization and adequate irrigation reduce plant stress and remove sources of infestation, while avoiding unnecessary use of broad-spectrum insecticides conserves predator diversity (Sharath et al. 2024).

5.2. Botanical acaricides

Plant-based acaricides and essential oils are attractive for mulberry because they generally degrade rapidly and pose fewer risks to silkworms and natural enemies. Botanical formulations based on *Spilanthes paniculata* and *Eichhornia crassipes* offer moderate control with favourable environmental profile (Ghosh, 2023). The effects of essential oil from eucalyptus, ocimum and rosemary, which exhibited strong repellency 70–84% (Sathyaseelan et al. 2020), while mentha and cymbopogon show moderate activity against *T. urticae*, Peppermint and clove oils, alone or combined with *Phytoseiulus persimilis*, can achieve over 90% suppression of spider mites on mulberry (Abdallah et al. 2015).

Leucaena glauca seed extracts hexane and dichloromethane caused high acaricidal activity against *T. urticae*, inducing 80.6% and 98.9% adult female mortality at 10000 ppm under no choice conditions and also showed oviposition deterrence, with 100% reduction in egg laying. In choice tests, concentrations from 100 to 10000 ppm showed good repellent effects, as <50% of mites and eggs were recorded and ovicidal assays revealed egg mortalities of 59.8%- 99.6% (Auamcharoen and Chandrapatya, 2015).

Acetone leaf extract of *Aloe barbadensis* exhibited strong acaricidal activity against *T. urticae*, with low LC_{50} values of 105 and 80 ppm, which reduced adult female longevity and fecundity, decreasing lifespan to 14.45 days and deterrent effect of 43% (Eleawa, 2013). The observations made by (Kruewong and Auamcharoen, 2023) found that hexane and methylene chloride extracts of Zanthoxylum myriacanthum fruits with limonene and sabinene as dominant compounds were highly effective against *T. urticae* and *T. truncatus* inducing 85.8% adult mortality at 12% concentrations, egg hatching capacity was suppressed by less than 50% and notable repellence of >65%.

The field efficacy of botanical oils; neem, mahogany, karanja oil were evaluated by (Rahman et al. 2016) and concluded that neem oil and mahoganu oil provided control of 60.55% and 55.89% respectively. Also, population assessments at 7 and 10 days after spraying confirmed sustained suppression of the mite. Neem seed extract reduced the population growth of *Polyphagotarsonemus latus* on chilli in a dose-dependent manner, with negative growth occurring at concentrations above 0.13 g a.i./L (Venzon et al. 2008)**.**

5.3. Biological control

Biological control is an essential tool in integrated mite management, particularly in residue-sensitive systems such as sericulture. Predatory mites such as *Neoseiulus longispinosus*, *N. indicus*, *Amblyseius swirskii* and *Euseius ovalis* (Eleawa, 2013)**,** *Phytoseiulus persimilis* (Auamcharoen and Chandrapatya, 2015), have been observed in mulberry plantations and can substantially reduce *P. latus* and *Tetranychus* populations, especially when conserved through reduced insecticide use.

Entomopathogenic fungi, notably *Hirsutella thompsonii*, have shown high efficacy against the broad mite *P. latus* on mulberry, achieving ≥90% population reduction on both upper and lower leaves (Kruewong and Auamcharoen, 2023), surpassing the chemical acaricide propargite 57% EC (Rahman et al. 2016). Greenhouse and field trials indicate rapid reductions in mite populations within four days of application.

5.4. Chemical control

The chemical control of mites in mulberry using conventional acaricides such as phosalone, dicofol, and endosulfan reported by (Sharath et al. 2022) was found to be effective against *Tetranychus* spp. and *Polyphagotarsonemus latus*, provided a strict waiting period of 15 days was maintained to avoid silkworm toxicity. He further demonstrated that selective acaricides, particularly propargite 57 EC at 1.5 ml L^{-1} and wettable sulphur 80 WP at 3 g L^{-1}, caused high mortality of eggs and active stages of *P. latus* while remaining safe for silkworm rearing. The effect of microbe derived acaricide Ambush 1.8 EC against *P. latus* studied by (Rahman et al. 2016) reported 80% reduction in mite infested plants.

Abamectin 1.9% EC and diafenthiuron 50% WP effectively suppressed mite and thrips populations on mulberry without inducing phytotoxicity or significantly reducing coccinellid predator populations. He also reported an improvement in mulberry leaf yield, highlighting the suitability of these selective acaricides for incorporation into IPM programs (Kenchappa et al. 2024). Abamectin (Vertimec 18 EC, 1.8%) induced 100% adult mortality without oviposition within 6 days, providing rapid and complete control (Venzon et al. 2008).

5.5. Integrated Mite Management (IMM)in mulberry

An effective Integrated Mite Management (IMM) strategy for mulberry should be built on early detection, weather- and threshold-based decision-making, host plant resistance, selective chemical interventions, biological control agents and botanical products. Monitoring efforts must focus on young upper leaves, especially the third to fifth leaves from the apex, and may employ visual grading scales for damage as well as simple counts of mites per leaf to guide interventions (Dar et al. 2012; Arunkumar and Srinivasa, 2021).

When economic thresholds are exceeded, selective acaricides such as, abamectin (1.9% EC) and diafenthiuron (0.05% WP) (Kenchappa et al. 2024) or propargite (57 EC @ 1.5 ml/l)and wettable sulphur (80 WP @ 2–3 g/l) (Sharath et al. 2022) can be used in rotation, in combination with or complemented by entomopathogenic fungi, *Hirsutella thompsonii* (1-1.2%) (Kumar and Varshney, 2020) and predatory mites, *Phytoseiulus persimilis* (Abdallah et al. 2015), while respecting silkworm safety and waiting periods (Maketon et al. 2008). Cultivating mite-tolerant varieties, such as Tr-10 (Gowda and Jagadish, 2025) and KNG (Dar et al. 2011), and integrating essential oils such as peppermint oil, and clove oil at 0.5% (Abdallah et al. 2015), will further reduce dependence on synthetic pesticides and enhance the long-term sustainability of sericulture.

6. Biotechnological approaches in mulberry mite management

Molecular and genomic tools are increasingly being applied to investigate pest adaptation, pesticide resistance, and host mite interactions enabling a deeper understanding. The development of mite resistant mulberry cultivars with modern approaches such as marker-assisted selection and genomic breeding facilitating the identification of resistance associated genes and quantitative trait loci linked to pest tolerance (Collard and Mackill, 2008; Varshney et al., 2005). Integrating these molecular approaches with conventional breeding can accelerate the development of resilient mulberry genotypes.

In parallel, genomic and transcriptomic studies of phytophagous mites have provided significant insights into their molecular biology and adaptive evolution; for example, chromosome-level genome assemblies of *Tetranychus urticae* have enhanced understanding of its genetic architecture and resistance mechanisms (Cao et al., 2024), while genome sequencing of *Tetranychus piercei* and *Tetranychus truncatus* has revealed genetic factors associated with environmental adaptation, host range expansion, and pest status (Chen et al., 2024). Functional transcriptomic analyses have further elucidated the molecular basis of acaricide resistance by identifying detoxification enzymes such as cytochrome P450s, glutathione S-transferases, and esterases, which play critical roles in pesticide metabolism (Dermauw et al., 2013; Koirala et al., 2024). Structural and functional investigations of detoxification enzymes in *T. urticae* have also highlighted potential molecular targets for the development of next-generation acaricides.

7. CONCLUSION

Mulberry (*Morus* spp.) is an economically important perennial crop, grown mainly as the exclusive food source of the silkworm (*Bombyx mori*), while also serving as animal fodder and a plant of nutritional and medicinal value. In recent years, mulberry cultivation has faced increasing pressure from phytophagous mite pests, which have become one of the most damaging biotic constraints affecting leaf yield and quality. Mite infestation causes biochemical and structural damage to leaves, leading to chlorosis, reduced photosynthetic activity, and deterioration of key nutritive components required for healthy silkworm growth. Even moderate levels of infestation can delay larval development and reduce cocoon weight, shell ratio, and silk filament length, resulting in considerable economic losses to sericulture farmers. Growing awareness of pesticide residues and the sensitivity of silkworms has shifted attention towards safer and more sustainable mite management practices. Improved knowledge of mite biology, pest plant interactions, and varietal responses has facilitated the development of selective and silkworm safe control options. The integrated use of selective acaricides, biological control agents, and botanical formulations provides effective mite suppression without compromising environmental quality or silkworm health.

7. Future Directions

Focussing on developing mite tolerant mulberry varieties, improving pest monitoring and forecasting, and strengthening field use of biological and eco-friendly control methods to protect mulberry leaf quality and ensure sustainable silk production under changing environmental conditions.

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Fig 1. Distribution of the mite on mulberry across the world

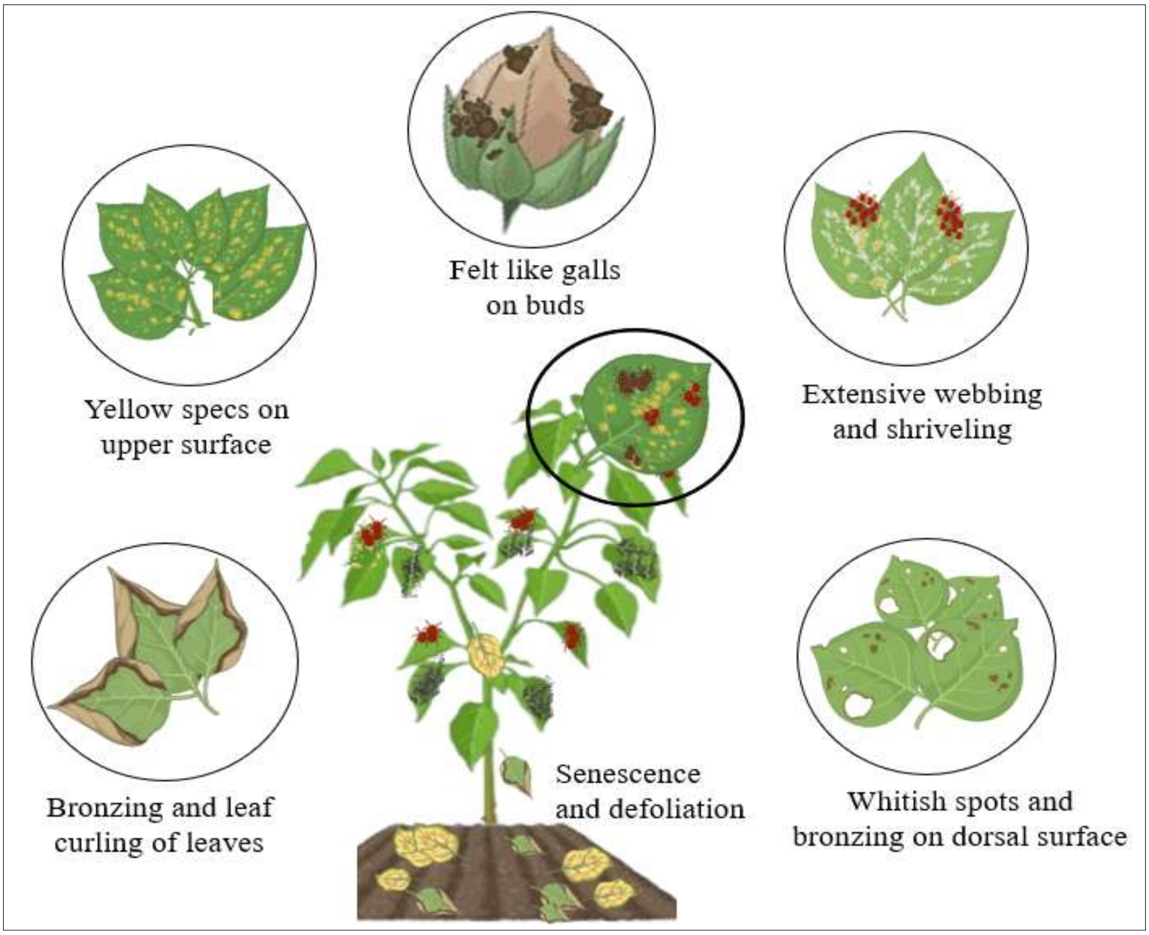

Fig 2. Damage symptoms on mulberry due to mite infestation

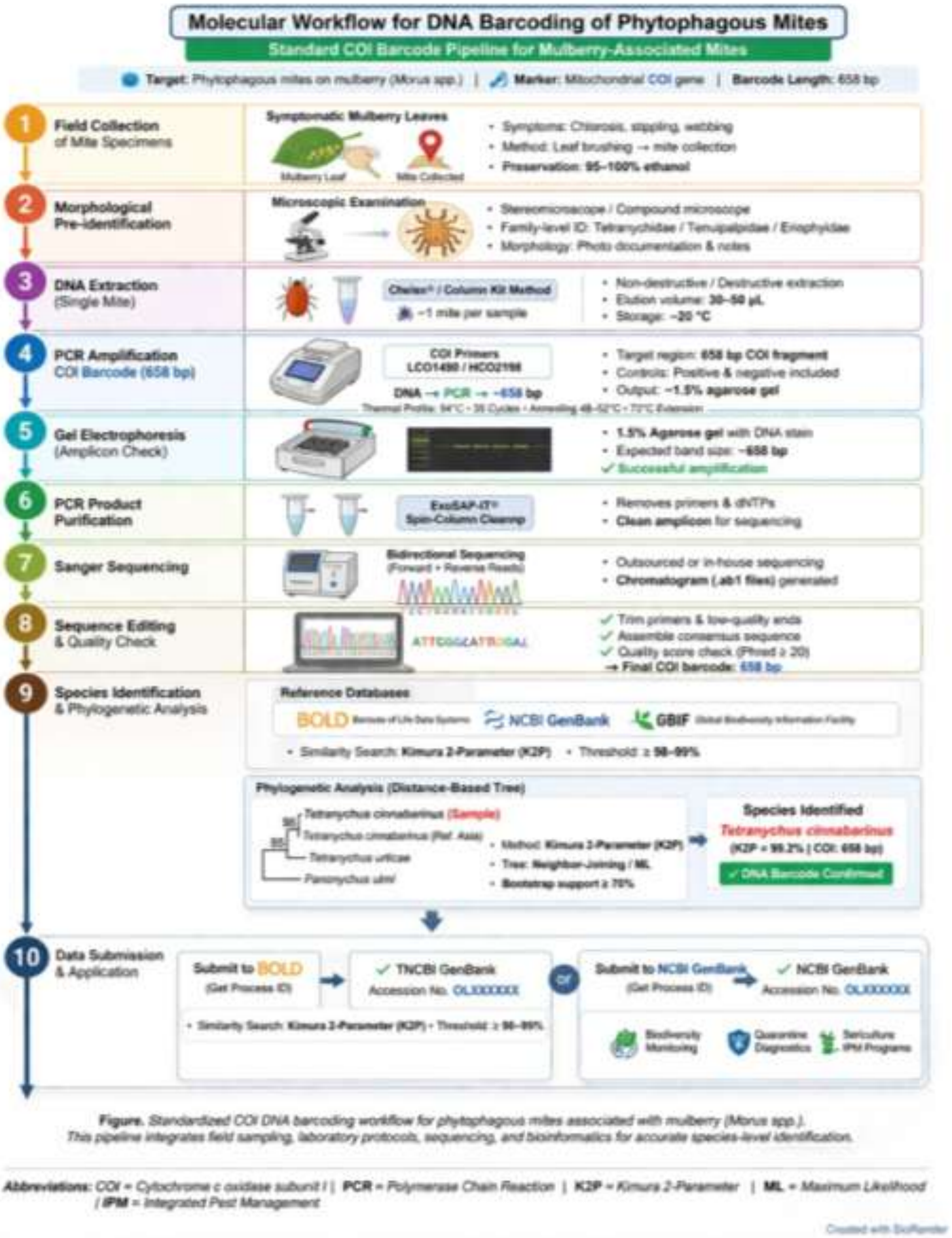

Fig 3. Workflow of COI-based DNA barcoding for mulberry-associated phytophagous mites, integrating specimen collection, morphological identification, molecular analysis, and database comparison (BOLD, GenBank) for accurate species identification and pest management.

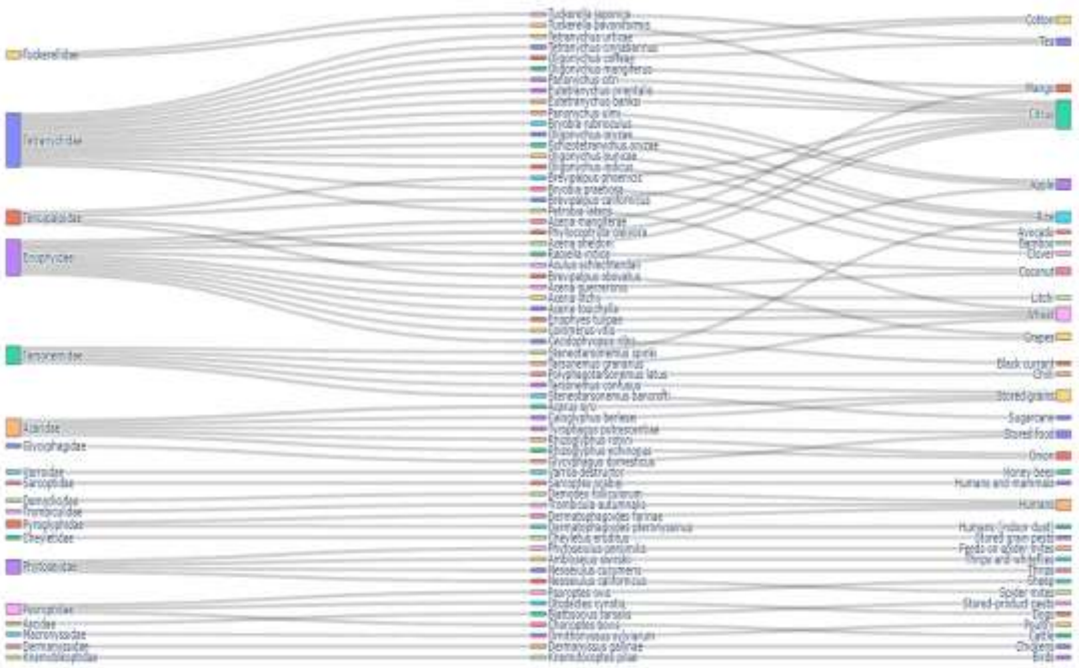

Fig 4. Sankey diagram illustrating the relationships among mite families, species, and their major host crops compiled from literature reports. Colored nodes represent taxonomic levels, while link widths indicate the strength of associations between families, species, and host plants.

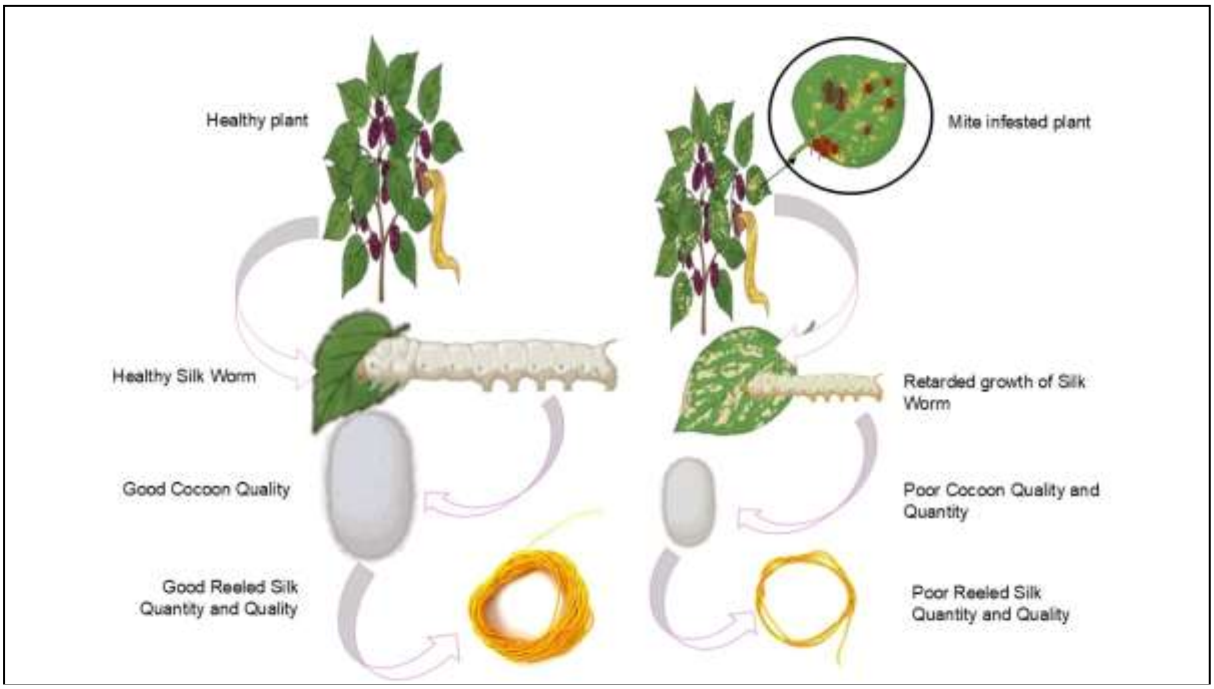

Fig 5. Healthy vs mite infested mulberry and its effects

Table 1. Mulberry Pests of economic importance

S. No.	Pest group	Insect species	Symptoms	References
Insect Pest				
1	Defoliators	*Diaphania pulverulentalis* Lepidoptera: Pyralidae	Leaf rolling, webbing, and skeletonization.	(Mahadeva, 2018)
		Spilosoma obliqua Lepidoptera: Erebidae	Irregular holes, and heavy defoliation.	(Sakthivel et al. 2019)

2	Sap-sucking insects	*Aleurodicus disperses* Hemiptera: Aleyrodidae	Yellowing, curling, honeydew, and sooty mould.	(Kumari, 2011)
		Pseudodendrothrips mori Thysanoptera: Thripidae	Silvery streaks, margin curling, and brittle leaves.	(Etebari and Bizhannia, 2006)
		Empoasca flavescens Hemiptera: Cicadellidae	V-shaped tip necrosis, chlorosis, and leaf drop.	(Sakthivel et al. 2019)
3	Stem and shoot borers	*Batocera rufomaculata* Coleoptera: Cerambycidae	Tunnelling, frass, dieback, and weakened branches.	
		Maconellicoccus hirsutus Hemiptera: Pseudococcidae	Deformed shoots, curling, and sooty mould.	
4	Soil pests	*Odontotermes* sp. Blattodea: Termitidae	Root bark scraping, wilting, and plant death.	

Table 2. Mite pests of mulberry

S. No.	Common name	Scientific name	Family	Symptoms	References
1	Bud mite	*Aceria mori*	Eriophyidae	Felt like galls on buds, leaf curling, anddeformation	(Narayanaswamy et al. 1996)
2	Broad mite	*Polyphagotarsonemus latus*	Tarsonemidae	Bronzing, rigidity, and distortion of young leaves.	(Arunkumar and Srinivasa, 2021)
3	Dark-red spider mite	*Tetranychus ludeni*	Tetranychidae	Yellow specks, bronzing, webbing, moisture loss.	(Sakthivel et al. 2019)
4	Two spotted spider mite	*Tetranychus urticae*	Tetranychidae	Stippled, whitish/bronze leaves, and defoliation.	(Ramegowda et al. 2012)
5	Kanzawa spider mite	*Tetranychus kanazawai*	Tetranychidae	Stippling, bronzing, webbing, and shrivelled upper leaves.	(Narayanaswamy et al. 1996; Dar, 2015; Gotoh and Gomi, 2003; Sharath et al. 2022)
6	Vegetable spider mite	*Tetranychus neocaledoinicus*	Tetranychidae		
7	Red spider mite	*Tetranychus telarius*	Tetranychidae		
8	Gladiolus mite	*Tetranychus equitorius*	Tetranychidae	Mottling, bronzing of leaves.	
9	Cassava mite	*Tetranychus truncatus*	Tetranychidae		
10	European red mite	*Panonychus ulmi*	Tetranychidae		
11	Oriental red mite	*Eutetranychus orientalis*	Tetranychidae	Whitish spots and bronzing on upper leaves, and senescence of leaves	(Narayanaswamy et al. 1996)